POWER ECONOMY IN THE FACTORY

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A BOOK FOR COST AND WORKS ACCOUNTANTS, AND ALSO FOR STUDENTS INTENDING TO ENTER FOR THE POWER GENERATION AND TRANSMISSION SECTION OF THE EXAMINATION OF THE INSTITUTE OF COST AND WORKS ACCOUNTANTS

BY

J. C. TODMAN

F.C.W.A.

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PREFACE

THOSE of us old enough to remember Victorian grandfathers will have frequently heard the proverb: "Take care of the pence and the pounds will take care of themselves."

There is no doubt that in a great many, probably a majority, of the factories at work to-day, pence are being wasted continuously; and that if this steady leak were stopped the result would go far towards helping to produce a dividend which is the inducement offered to the investor to provide the capital necessary to build up and extend industry.

Almost every factory uses power which is either generated on the spot or purchased as required and distributed throughout to the various points at which it is used. While other losses may occur only at intervals, any loss in the generation and transmission of power is practically continuous, and therefore if remedied only to a small extent, in time the saving will accumulate until it reaches a considerable figure.

Evidence exists that while steps have been taken to avoid waste in production, particularly at those points which require only general knowledge and common sense for their appreciation, sufficient attention is not always given to savings which may be obtained in the plants which require a certain amount of technical knowledge for a proper appreciation of their possibilities.

A technical man on the staff of a concern is not

usually employed unless he is fully occupied, and although he may appreciate what might be done in this direction, it is put off to some future time for investigation and consequently never done.

The managing director, as the representative of the employers, is usually on the lookout for improved efficiency, but unless he has at least some engineering and scientific knowledge he does not realize that the possibilities exist.

The annual expenditure of a business may be four times the capital invested, and a saving of 1 per cent of this expenditure might provide a dividend.

Waste of material is obvious to any one, wasted labour can be discovered by a qualified cost accountant, but waste power is never seen, it simply disappears as heat up a chimney or in some other form, and it is no exaggeration to say that in 90 per cent of the factory power plants in this country waste heat, often to a tremendous extent, is passing up the chimney and lost, never to be regained.

All power generated by heat engines is necessarily accompanied by some unavoidable loss of heat, but efficiency can be increased by reducing these heat losses to a minimum and making some use of the heat which is unavoidably rejected.

Only a small amount of scientific and engineering knowledge is necessary to see the possibilities, and this book is an attempt to condense such knowledge and present it in a form in which it can be assimilated by anyone of normal intelligence without the necessity to refer to any other source for scientific or engineering information.

Having set these limitations it is, of course, impossible to enter minutely into details, but the existence of such inefficiencies can be shown, the points at which they will be likely to be found indicated, and the nature of the remedy suggested.

The details of the work necessary for the reduction or abolition, if possible, of the waste will remain the province of the engineer with the assistance, perhaps, of the chemist.

The financial measurement of the results attained will be the work of the cost accountant.

At this juncture it is advisable to point out that those employed on this work must be properly qualified. Engineering has now become such a vast subject, that in order to be proficient in any particular branch it is necessary to specialize, and the man employed must have the necessary knowledge of this branch of the subject.

In the same way the cost accountant must be properly qualified. There is still a lack of appreciation among many employers as to what constitutes proper cost accountancy, and a "cost clerk" will not be capable of such work.

It is hoped, too, that a simple description of the plant used and its working will be useful to other non-technical members of the staff of a factory. Particularly this should apply to the cost accountant. He has to determine the allocation of the overhead charges for power and services, and the more he knows about its production and distribution the better he will be able to work intelligently without undue dependence on an outside source of information which may possibly

be biased on account of some particular point of view of the individual from whom it comes.

As far as possible all technical and scientific terms are defined and explained when they are first used. It is necessary to study a little simple science before proceeding to the power generation and transmission. The first three chapters are therefore devoted to very elementary mechanics, heat, and magnetism and electricity, which should carry the reader to such a point that he is able to understand and appreciate the remainder.

It is the earnest hope of the author that such understanding may result in action with a consequent improvement in production, a conservation of fuel through its more economical use, and thus prove a small contribution to the advancement of the industrial position of this country.

J. C. TODMAN.

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POWER ECONOMY IN THE FACTORY

CHAPTER I

SIMPLE MECHANICS

When you return from your holidays and carry a heavy trunk upstairs you perform "mechanical work."

It does not matter if the operation of carrying the trunk up takes half a minute or half an hour, the work done in either case is exactly the same. We say that one person is "quick at his work" and another "slow at his work"; these expressions imply that in measuring a certain *amount* of work time does not enter into the calculation.

Mechanical work is associated with motion in some form (sitting still and thinking is not mechanical work), a man carrying a load along, someone turning a handle, and a motor-car running along the road are all examples of the performance of work, and in all these examples there is a resistance offered to the motion.

We may therefore define mechanical work as being done whenever resistance to motion is being overcome through a definite distance.

In the examples the resistance to lifting is due to the weight of the trunk and the distance is the height through which it is lifted, the resistance to turning the handle is overcome through the distance the handle is moved, and the resistance to motion (not the weight) of the motor-car is overcome through the distance it moves along the road.

In engineering and most practical mechanical problems the resistance is measured by the force necessary to overcome it, expressed as the weight in lbs. the force would lift vertically, and the distance is measured in feet, the unit of mechanical work being thus the foot × lb., called the foot-pound, which is the work done when a resistance equal to a 1 lb. weight is overcome through a distance of 1 ft.

It is most important that the weight used for the measurement of a force should not be confused with the actual weight of the body moved; lifting a weight vertically through a distance of 1 ft. is a very different matter from moving it horizontally through 1 ft. In one case you are overcoming the resistance of gravity, in the other gravity does not come directly into the proposition.

The resistance to moving a train along a horizontal track is the wind pressure and rolling resistance. The wind pressure, we know from experience, increases rapidly as the speed goes up. The rolling resistance will depend upon the nature of the track. We know this, too, from experience, as it is much easier to push a truck along a level hard road than along a level sandy lane.

The rolling resistance for different surfaces has to be determined experimentally; on a good railway it may be about 6 lb. per ton weight of the train.

At very slow speeds windage may be neglected, therefore the mechanical work done in moving the train horizontally through a distance will be the rolling resistance × distance, whereas if the train were lifted vertically the work done would be the weight of the train × vertical distance.

We are now in a position to state the following formulae—

$$\underset{\text{(ft.-lb.)}}{\text{Work}} = \underset{\text{(ft.)}}{\text{distance}} \times \underset{\text{(lb.)}}{\text{resistance to motion}}$$

$$\text{Distance (ft.)} = \frac{\text{work (ft.-lb.)}}{\text{resistance to motion (lb.)}}$$

$$\text{Resistance to motion (lb.)} = \frac{\text{work (ft. lb.)}}{\text{distance (ft.)}}$$

The resistance to motion is only equal to the actual weight of the body moved when the motion is in an exactly vertical direction, such as a body lifted by a crane, a bucket drawn up a well, etc.; in other cases it is less than its total weight

POWER is the (time) rate of doing mechanical work.

When any racing motorist sets out to break a record he uses a car having the most powerful engine obtainable, and makes the weight as low as possible consistent with strength. The engine has to do work in overcoming the rolling resistance and wind pressure through a distance; the total rolling resistance decreases as the weight of the car, the wind pressure is reduced to a minimum by suitably shaping the body, and the powerful engine is put in to perform the work (resistance to motion × distance) in the minimum time.

When Watt was introducing the steam engine the power necessary to do the work of mine pumping, etc., was usually obtained by the use of horses, consequently he decided to rate the power of his engines by the number of horses they would displace so as to have a ready argument when pressing their adoption, and this led to the adoption of the horse-power as the ordinary commercial unit of power.

By trial he found that a good horse could perform about 22,000 ft.-lb. of work per minute, and by adding 50 per cent so as to give good measure he adopted the figure of 33,000 ft.-lb. per minute as his mechanical horse-power. This figure has continued to be used since.

We see, then, that an engine which does (33,000 × 5) or 165,000 ft.-lb. of work in 1 min. is a 5 h.p. engine;

if it does the same work in half a minute or twice the work in 1 min. it will be a 10 h.p. engine, thus—

A 5 h.p. engine will do 165,000 ft.-lb. in 1 min.
330,000 ft.-lb. in 2 min.
or 82,500 ft.-lb. in $\frac{1}{2}$ min.

Preparing formulae as before.

$$\text{Power (h.p.)} = \frac{\text{resistance (lb.)} \times \text{distance (ft.) per min.}}{33{,}000}$$

$$\text{Resistance (lb.)} = \frac{\text{power (h.p.)} \times 33{,}000}{\text{distance (ft.) per min.}}$$

$$\text{Distance (ft.) per min.} = \frac{\text{power (h.p.)} \times 33{,}000}{\text{resistance (lb.)}}$$

The resistance overcome is expressed in pounds, and as we have seen, the force necessary to overcome it is measured as the weight in pounds the force would lift vertically. If the engine is used for a crane its power in horse-power can be ascertained by the actual weight lifted multiplied by the vertical distance in feet through which the weight is lifted and divided by 33,000; on the other hand, many engines simply turn a flywheel, from which perhaps a belt is run to drive machinery, or pull a load such as a locomotive; in such cases we must ascertain the equivalent to a weight raised through a certain height.

Fig. 1 is a sketch of an engine with a weight *W* hung at the end of a rope round the flywheel.

Let the diameter of the flywheel be 7 ft., its circumference $7 \times \frac{22}{7} = 22$ ft., the weight = 300 lb., and the engine running at 100 r.p.m. The distance the weight moves in 1 min. will be 100 r.p.m. $\times$ 22 ft. = 2,200 ft., and the horse-power exerted will be

$$\frac{300 \times 2200}{33000} = 20 \text{ h.p.}$$

It is obvious from this example that we need not have troubled to think of the weight and rope arrangement. The power is represented by the pull in pounds at a point on the rim of the flywheel multiplied by the distance that point travels in 1 min.

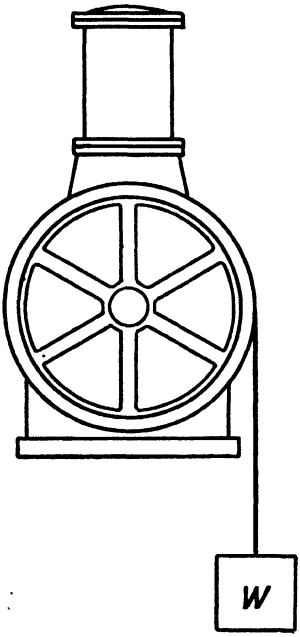


FIG. 1

Before leaving this engine example one other lesson may be learned. As power is the rate of doing work, in order to have the power output constant the rate per minute must be constant. The *work* done per minute by the above engine when developing 20 h.p. is

$$300 \text{ lb.} \times 2200 \text{ ft.}$$
$$= 660000 \text{ ft. lb.}$$

Supposing that the flywheel were only 3 ft. 6 in. or half the diameter, the distance travelled by the point on the rim would be only half that for a 7 ft. diameter flywheel, but when the engine is developing 20 h.p. the work is 660,000 ft.-lb. per minute, therefore at the reduced diameter the weight which it is capable of lifting will be

$$\frac{660000}{3\frac{1}{2} \times \frac{22}{7} \times 100} = 600 \text{ lb.}$$

That is, by halving the diameter of the flywheel the engine is capable of exerting twice the pull at a point on the rim, or, in other words, that when a pulley is revolving with a certain power driving it, the pull

which can be exerted will vary according to the distance at which it is taken from the centre, the nearer the centre the greater the pull.

This could be proved by taking a shaft mounted on bearings and free to turn (Fig. 2) and putting on it two pulleys one, say, 7 ft. diameter, and another of 3 ft. 6 in. diameter. On attaching a rope and weight to each on opposite sides it will be found that a weight of, say, 20 lb. on the small pulley is exactly balanced by a weight of half its value, 10 lb. on the large pulley.

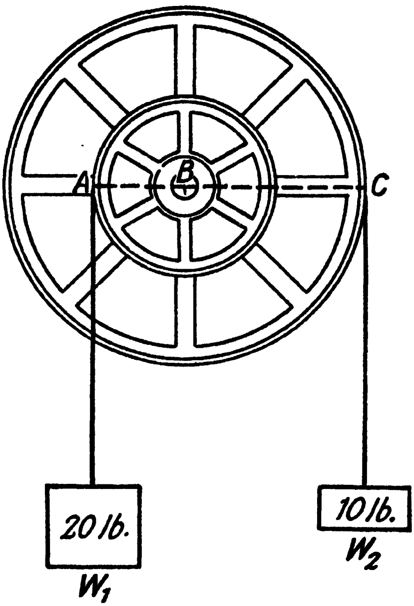


FIG. 2

This is the principle of the block and tackle used for lifting heavy weights, and from the diagram it will be seen that it also explains the lever. Supposing that all the essential parts of this arrangement consisted of a bar ABC, which constitutes a lever using B as the fulcrum, a pressure of 10 lb. exerted downwards at C will raise a weight of 20 lb. at A. Now we can find another formula. We know that distance $BC = 2AB$ and weight $W_1 = 2W_2$.

So $AB \times W_1 = BC \times W_2$

or $$W_1 = \frac{BC \times W_2}{AB}$$

or $$W_2 = \frac{AB \times W_1}{BC}$$ and so on.

Having obtained the work done, from what we know of power, we can find the horse-power required.

If a train is travelling up a gradient we shall have to add to the above result for work done in moving it along a level surface, the total *vertical* height through which it is lifted multiplied by the weight of the train in pounds.

Force. Up to the present we have not used the term "force"; motion is necessary to work, but force can be exerted without any resulting motion.

If a weight is too heavy to lift you can exert force trying to lift it, but no movement will result. Supposing you exert more force and just manage to lift it, work is done by you, and if you drop it, as it falls to the ground, work is done by the weight; in other words, the energy which you have put into the weight by lifting it is given out again as it falls and hits the ground. Force is exerted again by the air resistance as the weight falls and by the resistance of the ground to its further movement.

We can therefore define force as that which either tends to produce or produces motion in a body, or which tends to change or changes the motion of a body.

Do not forget that if a body is stationary it will remain so for ever unless some force is applied to move it, and that if a body is moving it will continue in motion for ever unless a force is applied to stop it or change its motion.

The first case is obvious, but it is not quite so easy to see the second.

Imagine a truck running on a rough road, it will be fairly hard to push; try it on a very smooth road and it will be easier; push it on rails and it will be easier still. Now imagine it is just lifted off the rails, say, by the attachment of a balloon. The only resistance to horizontal movement will be the wind resistance, or its resistance to passage through the air.

If you could remove the air, and if under these circumstances the balloon could still lift the truck, that resistance would be gone, and there being nothing to impede its progress, once it is started it would go on moving until stopped by some force applied to it.

Energy. Energy has been defined as the capacity of a body for doing work. We have just seen that a weight lifted from the ground has obtained energy which it can give out as work when it falls again. Energy which is stored up in this way, or in water by virtue of its being at the head of a fall, or in coal by virtue of its property of combustibility, is called *potential energy*. That is, it is stored up and can be released and used at any convenient future time.

There is another form of energy. If a railway train rushes into a terminus and the brakes are not applied, even if the steam is cut off, it will do a considerable amount of work represented by damage before it is brought to a standstill.

This train has energy by virtue of its motion, but it retains the energy only as long as it is moving, consequently it cannot be stored for use at some indefinite future period. Energy possessed by a body by virtue of its weight and velocity is called *kinetic energy*.

A practical application of the utilization of such energy is found in the flywheel, or a windmill, which utilizes the kinetic energy of the wind.

Velocity. Velocity is defined as the speed at which a body moves. The velocity of a body moving through space is usually measured in feet per second.

The velocity of a body such as a flywheel or pulley rotating about its own centre is measured in revolutions per minute, expressed r.p.m.

If you are driving a motor-car of low power up a steep hill you will come to a point when, in order to continue progress, you must change gear. Why is

this? We know that speed is a factor of power. As the engine slows down it gives less power; as we want to obtain the maximum power from the engine it must therefore run fast. For the same reason the slower the pace at which we ascend the hill the less the power required, so we must combine the two.

In a small car the engine will run and give its maximum power at about 3,000 r.p.m. Calculate the r.p.m. of the car wheels at, say, 20 m.p.h. It can be done as follows: all that is necessary is to divide the distance travelled in 1 min. by the circumference of the wheel.

$$\text{Distance in yd. travelled in 1 min.} = \frac{\text{speed in m.p.h.} \times 1760}{60} = \frac{20 \times 1760}{60} = \frac{1760}{3}\text{ yd.}$$

Assuming that the diameter of the wheel is 27 in.

$$\text{Circumference of wheel in yd.} = \frac{27}{36} \times \frac{22}{7} = \frac{33}{14}\text{ yd.}$$

$$\text{R.p.m. of wheel} = \frac{1760}{3} \div \frac{33}{14} = \frac{1760}{3} \times \frac{14}{33} = 249 \text{ approx.}$$

We see now that the speed of the wheels must be only about one-twelfth of the speed of the engine. To attain this all cars are provided with a gear reduction between the engine and the wheels. This gear reduction is made so that it can be varied within limits by the movement of the gear lever changing the particular wheels which are in mesh or working together.

To get up the hill slowly, then, and thus make the best of the power of the engine at a slow speed, all

that is necessary is to increase the gear ratio by going into low gear.

Torque. There is another way of looking at the question of gearing. (Refer to Fig. 1.) We found that a 20 h.p. engine running at 100 r.p.m. could just exert a force of 300 lb. tangential to the rim of its flywheel 7 ft. in diameter or 3 ft. 6 in. radius, and that if the diameter were halved it would balance 600 lb. at 1 ft. 9 in. radius, so we can indicate a certain power at a certain speed in terms of a force acting tangentially to a radius from the centre.

It is usual to reduce this unit to a force acting at a radius of 1 ft. A simple proportion sum will show that the engine referred to, when exerting 20 h.p., would balance, at a radius of 1 ft., a weight of

$$\frac{3 \text{ ft. } 6 \text{ in. } \times 300}{1 \text{ ft. } 0 \text{ in.}} = 1050 \text{ lb.}$$

This figure is called torque, and is sometimes expressed in ft.-lb.; in order to avoid confusion with work, which is measured in ft.-lb., it is by many termed lb.-ft., a much better expression.

Thus, we should say an engine giving 20 h.p. and running at a speed of 100 r.p.m. gives a torque of 1,050 lb.-ft. And this torque is constant throughout the transmission from the point at which the power is generated to the point of its application, providing that the speed of the shaft is not changed.

If the speed is increased the torque is reduced in proportion; if the speed is decreased the torque is increased.

Reverting to the motor-car illustration it is obvious that the force pushing the car up the hill is the tangential force exerted by the tyre of the driving wheel on the road surface. This force is dependent on the torque in the back axle on which the wheel is mounted.

If the power and speed of the engine remain the

same, then by reducing the speed of the back axle we shall obtain more torque, and, so to speak, more push up the hill from the action of the tyre on the road.

There is gearing, either belt, chain, rope, or of other types in every factory, and if we know the torque in a shaft transmitting power we can, by a very simple calculation, obtain the pull or tension in a belt on a pulley driving or driven from that shaft whatever its diameter.

Thus—

The torque in a shaft is 80 lb.-ft. On it is mounted a pulley 4 ft. diameter which carries a driving belt. What is the tension in the belt?

$$\text{Tension in belt} = \frac{80 \text{ lb.-ft. (torque)}}{2 \text{ ft. (radius of pulley)}} = 40 \text{ lb.}$$

This figure of 40 lb. really represents the difference in tension between the driving side and the slack side. It is obvious that there must be some tension of the slack side to enable the belt to drive. The actual tightness of a belt will vary from time to time according to the amount of stretch, and the length at which it is originally made, and is not usually measured in a factory, the practice being to run a belt tight enough to drive, and when through stretching it eventually acquires considerable slip, it is shortened or taken up by other means.

The formula to obtain the torque of an engine can be constructed from what we have learned so far, and is—

$$\text{Torque in lb.-ft.} = \frac{\text{h.p.} \times 33{,}000}{\text{r.p.m.} \times 2 \times \frac{22}{7}}$$

Another useful formula to remember is for relative speeds of shafts when one is driving another either by belt, gear wheels, or chain.

If belt drive—

R.p.m. of driving shaft × diameter of pulley driving shaft = r.p.m. of driven shaft × diameter pulley on driven shaft.

If gear or chain drive—

R.p.m. of driving shaft × No. of teeth in wheel of driving shaft = r.p.m. of driven shaft × No. of teeth in wheel of driven shaft.

Summary of Chapter I

Work is done when in a movement through space a resistance is overcome.

The unit of work is the foot-pound, a resistance equivalent to a weight of 1 lb. overcome through a distance of 1 ft.

Power is the rate at which work is done. 33,000 ft.-lb. of work performed in 1 min. is 1 h.p.

Force is that which moves or tends to move a body or changes or tends to change its motion. It is measured in pounds as the equivalent weight which it would support.

Energy is the capacity for doing work and is either Potential or Kinetic. Potential is stored energy which can be utilized at any time in the future. Kinetic energy is energy acquired by a body by reason of its velocity and is only available for so long as it retains its velocity.

Velocity is the speed at which a body moves, and is usually expressed in feet per second, miles per hour, or revolutions per minute.

The greater time occupied in performing certain work the less the power required.

Torque. The tangential force exerted by a rotating body measured at a certain distance from its axis. Usually expressed in pounds-feet, being measured at 1 ft. radius.

Speed is changed by means of belt, rope, chain, or other forms of gearing.

CHAPTER II

SIMPLE HEAT

When you were a very small child you most certainly made your first acquaintance with heat by burning yourself, and you have probably since wondered what heat is. The ancient Greeks wondered too; they thought that it was a mysterious fluid which changed the form of substances. Ever since then men of science have been inquiring, and theories have been built up only to be destroyed in the light of new knowledge.

Whatever it may be, it is fairly safe to assume that it is some form of motion, and, as a hot body does not move, that it is an internal motion of the particles or molecules of which the body is composed. As long as the body is cool enough to be solid these particles remain within the natural form of the body.

Remember that a possible explanation of the liquefaction of bodies by heat is that the hotter a body becomes the more rapidly do the particles move, and consequently have less tendency to hold together, until finally the motion becomes so great that they will not hang together at all and the liquid becomes a gas which has no shape, spreading in every direction until it reaches the limits of the vessel in which it is confined.

Just as a moving body has energy by reason of its weight and velocity, so a body may have energy by reason of its weight and temperature.

If you buy a pound of nails on a cold day in the winter and keep them untouched until a hot day in the summer they will still weigh the same, although their temperature has gone up; in other words, they are

hotter. Therefore we know that heat has no weight. It is not a material substance.

We can prove this better perhaps by taking a pound of ice and melting it to water. A considerable amount of heat will be absorbed in the process, but only 1 lb. of water is produced; in the same way if we continue to add heat until the water is all changed to steam, making sure that no steam escapes, we shall have just 1 lb. of steam.

We know that power can be obtained from a waterfall, and that the power obtainable, if the quantity of water falling remains the same, will depend on the height of the fall, commonly termed the "head."

The water at the top has potential energy by virtue of its weight and head. As it falls it gives up its energy to the water-wheel or turbine, and on arrival at the bottom the energy is gone: it has been converted into mechanical work.

In the same way a hot body has potential energy by virtue of its temperature above surrounding objects which are normal; as it cools it can be made to produce mechanical work until its temperature has become reduced to normal.

The water which has reached the bottom of the fall has lost its energy relative to that particular fall, but if, later on, on account of the general level of the surrounding country being lower another fall is formed, the water has potential energy relative to the new level.

In the same way a hot body which has given up its energy on account of its temperature having fallen to the normal of its surroundings can still produce further mechanical work if placed in a region of lower temperature.

Water, if permitted, always flows from a high level to a lower level. Heat always flows from a body at a high temperature to a body at a lower, until they are both at the same temperature.

Almost everyone knows that in an open vessel water boils at 100° C. or 212° F.; this is known as the boiling point of water, and however long it boils its temperature is still the same although heat is continually being put into it. Now, perhaps, we realize the difference between temperature and heat.

The temperature of a body is the degree or intensity of its hotness. Whereas heat would represent the quantity of heat to be transferred to a body in order to raise its temperature. For instance, twice as much heat is required to boil a quart of water as would be necessary to boil a pint, but the final temperature is the same in each case.

Heat can be produced in various ways, but always by the conversion of some form of energy.

The primitive way of producing fire was by rubbing sticks of wood together or rotating a stick in a recess in a block of wood. In this case the mechanical work supplied was practically all converted into heat by friction, and raised the temperature sufficiently to cause chemical action or combustion of the tinder or wood dust formed, and consequent fire.

A rapid succession of blows from a hammer on a piece of metal will cause it to become hot.

The most general method of obtaining heat is by chemical action, which is always accompanied by the liberation or absorption of heat.

Combustion, or fire, as generally understood, is the combination of Carbon, either pure or in some of its compounds, with the Oxygen in the air. (This is not strictly true: there are other forms of combustion, the Oxyhydrogen blow-pipe, for instance; but for general heating purposes they may be neglected.) When this takes place heat is given off or perhaps it would be more modern to say that heat waves are produced which raise the temperature of surrounding bodies.

The unit of quantity of heat is one British Thermal

Unit, commonly abbreviated to B.Th.U., and is the quantity of heat required to raise the temperature of 1 lb. of water through 1° F. (The particular degree between 39° to 40° F. has been chosen as it has been found that there is a slight variation at other points in the scale.)

In passing, it is as well to mention that the **therm** is 100,000 B.Th.U.'s. Thus, when we buy 1 therm of gas we are supplied with gas which, on combustion under perfect conditions, would be sufficient to raise the temperature of 100,000 lb. of water through 1° F. or 50,000 lb. 2° F., and so on.

The gas company will state the heat generated per 1 cub. ft. of gas; for instance, the South Metropolitan Gas Company supplies gas giving 560 B.Th.U. per cubic foot. This is 560,000 B.Th.U. per 1,000 cub. ft. or 5·6 therms per 1,000 cub. ft. This is known as the calorific value of the gas. By analysis of a fuel such as coal of a certain grade its calorific value can be ascertained, and is of great importance in comparing the qualities of various grades of supplies.

A definite amount of mechanical work can be converted into a definite amount of heat. The maximum amount of heat obtainable from work was determined by Joule in the middle of the eighteenth century. His experiments extended over a period of nearly 30 years and cannot be described here. The principle on which he worked was to absorb mechanical work by friction and measure the heat produced. He found that—

1 B.Th.U. is equivalent to 772 ft.-lb.

As 1 therm = 100,000 B.Th.U.

1 therm will supply

$$\frac{772 \times 100,000}{33,000} = 2,340 \text{ h.p. (approx.) for 1 min.}$$

or 234 h.p. for 10 min.

or 1 h.p. for 2,340 min.

Modern measurements give 778 ft.-lb. as a more accurate value for Joule's equivalent for 1 B.Th.U.

This is all very nice and theoretically true; unfortunately in practice the losses which take place between the fuel and the mechanical power in a steam generating plant are so tremendous that while, theoretically, from 1 lb. of coal per hour we should with 100 per cent efficiency obtain about 5 h.p., actually we produce about 1 h.p. and are doing quite well. While an efficiency of 100 per cent is theoretically impossible, what scope for improvement there is in the methods for the conversion of the potential energy of coal into the mechanical horse-power now being used on such a great scale. Huge savings would result from even a small increase in efficiency.

Heat plays such an important part in the generation, transmission and utilization of power, also in maintaining the comfort and health of all, that a study of its transmission and generation is necessary to a proper understanding of the production and application of mechanical power.

We have noticed how the unit for a quantity of heat has been fixed: now, what is to contain that quantity? —as although heat is not a material substance, if it is to be stored, matter is required to hold it.

Heat is stored by raising the temperature of a body and is given out when opportunity is given for the temperature to fall.

How much heat will a body hold? As far as we know, as much as you like to put into it; but putting heat into a body changes its state, solid to liquid, liquid to gas; and it is not convenient always to change its state. Further, the same quantity of heat will not always raise the temperature of equal volumes or weights of different substances by the same amount.

One B.Th.U. is the amount of heat required to raise the temperature of 1 lb. of water through 1° F., but

only about $\frac{1}{2}$ B.Th.U. would be required to raise the temperature of 1 lb. of wood through the same amount; and about $\frac{1}{10}$ B.Th.U. would be sufficient for the same weight of iron. Brickwork would require about $\frac{1}{5}$ B.Th.U. per lb. As in heating a room, all its contents, walls, etc., will be brought to about the same temperature, we see that the material from which it is built and the nature of its contents will be factors of the amount of heat required. Another factor will be the rapidity with which heat is lost by transference outside the room; this will be dealt with later.

The ratio of the amount of heat required to raise the temperature of a substance through a definite number of degrees to the amount of heat required to raise the temperature of an equal weight of water through the same number of degrees is called the *specific heat* of the substance.

Thus the specific heat of those substances mentioned would be—

Water: sp. ht.		=	1 or in decimals			1·0
Wood:	,,	=	$\frac{1}{2}$	,,	,,	0·5
Iron:	,,	=	$\frac{1}{10}$	,,	,,	0·1
Brick:	,,	=	$\frac{1}{5}$	,,	,,	0·2

Tables giving specific heats of various substances will be found in most engineering handbooks.

All this is true for so long as the substance remains in the same state, either solid, liquid or gas, throughout the operation, but if a change takes place something else enters into the calculation.

If we try the experiment of heating water from the state of ice at 0° F. to steam at, say, 220° F., we find, first, that as we apply heat to the ice we gradually raise its temperature to 32° F. (melting point); to raise the temperature of 1 lb. of ice through 1° F. requires about $\frac{1}{2}$ B.Th.U., therefore its specific heat is 0·5, not the same as water.

When 32° F. is reached, the ice begins to melt, and continues to melt for so long as heat is applied, but *the*

temperature is not raised until all the ice is melted. Directly all the ice becomes water the temperature rises again, this time through 1° F. for every 1 B.Th.U. applied, until at 212° F. the water boils, that is, changes its state again. The vessel must be closed so that the steam cannot escape, but provided with means to allow expansion and remain at atmospheric pressure. As we continue to apply heat the water changes to steam, but once again, until all the water is changed to steam, no increase in temperature takes place. After the water has all become steam, we find that about ½ B.Th.U. again raises the temperature through 1° F., therefore the specific heat of steam is also different from that of water. The actual figures are—

Ice = 0·504. Water = 1·000. Steam = 0·480.

Where has all the heat disappeared to that is apparently lost when the state of the water was changed? It has been used in doing work in re-arranging the molecules from which the water is composed. Just as the heat used in raising the temperature is given up when the temperature is lowered, so the heat used in changing the state of a substance is given up when the state is changed in a reverse direction. This heat is known as *latent heat*.

Substances differ in their latent heat and, further, many have a *latent heat of fusion* and a *latent heat of evaporation*.

The latent heat of fusion is the amount of heat which is required to change a unit weight of a solid to liquid without an alteration of temperature.

The latent heat of fusion of ice is 144·0 B.Th.U. per lb.

The latent heat of evaporation is the amount of heat which is required to change a unit weight of a liquid to gas without an alteration of temperature.

The latent heat of evaporation of water is 966·6 B.Th.U. per lb. (at atmospheric pressure).

Now we are in a position to see how mechanical energy can produce ice in a refrigerator.

The electric motor, by means of a pump, compresses a gas, usually ammonia, until it becomes liquid, giving out its latent heat, which is dispersed in a suitable cooler. By reducing the pressure the liquid gas is allowed to evaporate and change its state; in doing so it absorbs a great quantity of heat without changing its temperature. The heat absorbed is extracted from surrounding objects, lowering their temperature and consequently freezing them.

The importance of the specific and latent heat in dealing with a steam plant is obvious, and its application will be given later.

The transference of heat from one body to another has been mentioned several times, and it is now necessary to consider how this takes place.

If you put a poker in the fire and allow the end to become and remain red-hot, the other end of the poker which is not in the fire will become very hot too; and particularly if the poker is short, if you take hold of it you will burn your hand.

The heat has been transferred through the steel of which the poker is made from the red-hot end to the handle.

This form of transference of heat is called *conduction*.

We know that we receive heat from the sun, although for a great part of the distance between us there is no matter through which it can be conducted.

This form of transference of heat is called *radiation*.

Hot air rises; if you blow some smoke over a hot water pipe, directly it arrives above it you will see it being carried up by the hot air. Neither radiation nor conduction would raise it; what happens is that air is heated when in contact with the hot pipe, it then

rises and gives up its heat to other air and bodies in its path as it moves past them.

This form of transference of heat is called *convection*, and can only take place in liquids or gases.

Heat is transferred by all three methods, from a furnace to water in a boiler.

The heat of the fire is conveyed to the boiler plates partly by radiation and partly by convection of the hot gases.

It is conveyed through the plate to the water by conduction from the outside to the inside surface of the boiler plate.

It is conveyed from the inside surface to the water in contact and throughout the whole body of the water in the boiler by convection.

If you walk round a room which has no artificial heating and put your hand on a metal or stone object you will say that it feels cold. Touch wood and you will think that it is not so cold. Feel a woollen covered cushion and you find it warm. Now the terms warm and cold are usually connected with temperature, and if you walk round with a thermometer taking the temperature of the various objects you have touched you will find that they are all at the same temperature.

Supposing the room were in the tropics and the general temperature above that of the human body, the apparent conditions would be reversed: the metal or stone would feel the hottest, the wood cooler, and the cushion the coolest.

Try an experiment as follows: Take three basins placed in a row. Fill basin *A* with water as hot as you can possibly bear with your hand, basin *B* with warm water, basin *C* with very cold water. Hold one hand in basin *A*, and the other in basin *C*, for some time until one hand is hot and the other cold.

Now put both hands at the same time in the warm water in basin *B*.

To the hand that was in basin *A* the water feels cold; to the other hand it feels hot. Why is this?

Because the sense of touch is a very poor instrument for the estimation of temperature, but it is good at distinguishing variations in the conductivity of heat by different substances. Remember that heat flows from a body at a high temperature to a body at a lower temperature until the temperatures are equal.

Metal is a good conductor of heat, and if it is colder than your hand it absorbs heat from your body much more quickly than wood or wool, which are poor conductors.

If the metal is hotter than your hand it gives up its heat much more quickly than the bad conductors. Temperature in itself will not cause a burn, but a certain quantity of heat is necessary to produce the chemical changes set up; the metal can supply the heat quickly because the whole quantity of heat which it contains can travel rapidly to the point of lower temperature which is in contact with it. Whereas if a piece of wood is at the same high temperature as the metal it will not cause a blister unless the hand is in contact for a considerable time, because the wood is a bad conductor of heat and the necessary heat units which it contains cannot travel sufficiently quickly to the point of contact with the hand.

The converse is also true, and metal cooler than your hand will absorb heat units quickly because the heat can be distributed rapidly throughout the whole of the metal; on the other hand, wood or a bad conductor cannot accept the heat so quickly on account of the slowness of distribution through its bulk.

It is highly probable that heat is transferred by waves. Radiant heat is transmitted by waves in the ether; these waves are similar to, but of a different length from, the electrical waves which are used for transmitting wireless signals.

Conducted heat may be actual waves causing movements of the molecules of the substance which is transmitting the heat.

Convected heat is really transmitted by small amounts of heat being taken up by a succession of particles of a gas or liquid which transfer themselves to some other place and deliver the heat to some other body.

The rate at which radiant heat is absorbed or emitted by a body depends on the nature of its surface. At medium temperatures such as that of boiling water it is found that, providing the surface is dull, colour has little influence on the rapidity of radiation, therefore hot water pipes for heating purposes can be painted either black or white, but the surface must be matt. A shiny paint such as copper or aluminium should not be used.

A common example of the prevention of the radiation of heat by using a highly polished surface is the dish cover used to keep food hot. The better and higher the polish the longer the food is kept warm.

Radiant heat can pass through a vacuum, which is an absolute bar to conducted or convected heat.

At temperatures normally met with on earth the radiation of heat is very small. Conduction and convection are the usual means of heat transmission; at boiling point radiation and convection from metal surfaces are equal; at furnace temperatures radiation is the most important factor. As we have seen, the metals are generally good conductors of heat, and non-metallic substances good insulators. Gases and liquids are useful as convectors of heat. To conserve heat, such as that of steam in a pipe, we coat the pipe with a material which in itself is a bad conductor and which preferably contains innumerable small air pockets or cells, because air is an excellent heat insulator, and providing it cannot circulate, as in the case when it is

locked up in the surrounding material in small cells, convection currents cannot be set up, and finally we paint the outside of the covering with a glossy white or aluminium paint to reduce radiation.

The heat insulating vacuum flask keeps food hot or cold because it consists of a double glass vessel between the walls of which is a vacuum; excepting through the neck and stopper there can be no conduction or convection of heat, and owing to the inside of the glass container being silvered, radiation is retarded.

Heat, we know, causes matter to expand and alter its volume, but not its weight; in scientific language this is known as a change of density.

A cubic foot of air at 100° F. will weigh much less than a cubic foot at 0° F., and the same in a lesser degree applies to water. This is why hot air or hot water always rises to the top, and is the reason for the circulation of convection currents.

If you are heating water by a gas ring heating the centre portion of the bottom of a kettle, the water in contact with the hot metal is heated by conduction and rises to the top, its place being taken by the colder water coming in from the sides, and this process of circulation continues until the water boils. The same principle causes the circulation in boilers and hot water heating systems.

The expansion of solids by heat may be illustrated by the necessity for leaving a space between consecutive rails on a railway to allow for expansion in hot weather, the expansion joint fitted in a line of steam pipe is also to allow for the difference in length caused by the variation in temperature between hot and cold.

It is interesting to note that it is not usual to allow a space at the joint of tramway rails because they are embedded in the ground and not therefore so subject to temperature variations, the temperature of the earth just below the surface remaining fairly constant,

and further, any increase in temperature due to heat from the sun would be conducted away by the surrounding earth and concrete.

We are in the habit of referring to the boiling point of water as being 212° F. or 100° C. This, in common with many other everyday expressions, is subject to qualification. We know that the earth's atmosphere has weight, and consequently exerts pressure. The pressure of the atmosphere is measured by the barometer. We are so used to pressure measured in pounds per square inch, that the barometer giving readings in inches is apt to be misleading.

We often find that instruments which were invented before science had made much progress have strange features which have survived and will remain, because any alteration would necessitate an enormous amount of work in the revision of accumulated data and tables.

The early barometers consisted of a mercury column in a glass tube supported by atmospheric pressure; as the pressure varied so the mercury rose or fell in the tube. The scientists of that day simply measured the height of the column to indicate the state of the barometer or otherwise the pressure of the atmosphere.

A height of 30 in. represents almost exactly a pressure of 15 lb. to the square inch (actually 14·7 lb. per square inch). This pressure is commonly termed one atmosphere, thus 30 lb. per square inch would represent two atmospheres.

Now, as pressure affects the boiling point, we should say that at a pressure of one atmosphere water boils at 212° F. or 100° C. The higher we rise above sea-level the less the atmospheric pressure, and it is found that on a high mountain owing to the decreased pressure, water boils at such a low temperature that an egg cannot be cooked by boiling.

As an indication, at a pressure of 5 lb. water boils

at 162° F.; at one atmosphere, 212° F.; at two atmospheres, 250° F.

The steam pressure gauge indicates in pounds per square inch pressure above normal atmospheric pressure; it is therefore necessary to add 15 lb. to the reading if it is desired to ascertain the pressure above 0 lb. per square inch; pressure indicated above this zero is known as *absolute pressure.*

Summary of Chapter II

A body has energy by reason of its heat.

Temperature is the degree of hotness caused by the amount of heat in a body.

Heat is produced by the expenditure of some form of energy. The quantity of heat is measured in British Thermal Units, 1 B.Th.U. being the amount of heat required to raise the temperature of 1 lb. of water through 1° F.

Equal volumes or weights of various substances require different amounts of heat to raise their temperature by an equal amount.

Specific Heat is the term applied to the ratio of the amount of heat required to raise the temperature of unit weight of a substance through a definite number of degrees to the amount of heat required to raise the temperature of the same weight of water through an equal number of degrees.

The Latent Heat of Fusion is the heat used in changing the state of a body from solid to liquid, the temperature remaining constant throughout.

The Latent Heat of Evaporation is the heat used in changing the state of a body from a liquid to a gas, the temperature remaining constant throughout.

Heat flows from a hotter to a colder body, and can be transferred by Radiation, Conduction or Convection.

Radiation takes place through a vacuum.

Conduction takes place between bodies in contact.

Convection takes place by the flow of liquids or gases.

Metals are generally good conductors of heat. Non-metals are generally insulators of heat.

A variation in pressure affects the boiling point of liquids.

phenomena and make magnetic and electrical measurements.

Faraday compared lines of force to stretched elastic, and this is a very useful comparison as they always

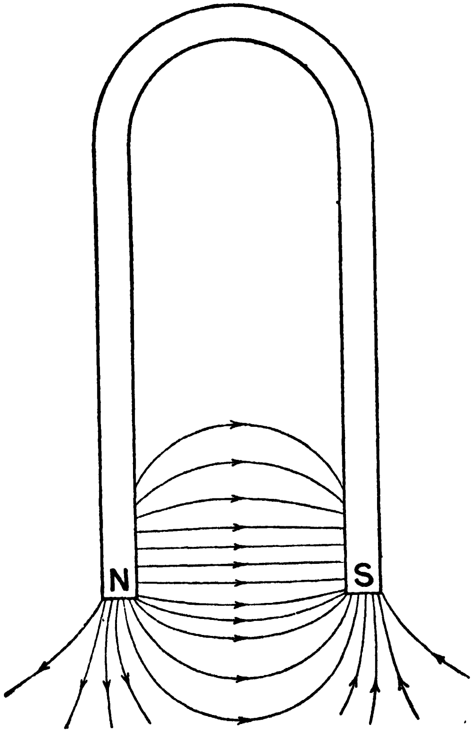


Fig. 3. Magnetic Field Round the Poles of a Horse-shoe Magnet

take the shortest path and resist any attempt to push them from that path; further, this illustrates the attractive force.

Reverting to the diagram of lines of force which is obtained with a horse-shoe magnet if the same experiment is tried with the keeper in position across the

poles, we shall see, as in Fig. 4, that the magnetic field has practically disappeared.

If a piece of brass or any material other than iron is substituted for the iron keeper, we find that the field is there as before as in Fig. 3.

This is because iron offers an easier path than air to the magnetic lines, and consequently when the iron keeper is in position the lines are concentrated inside

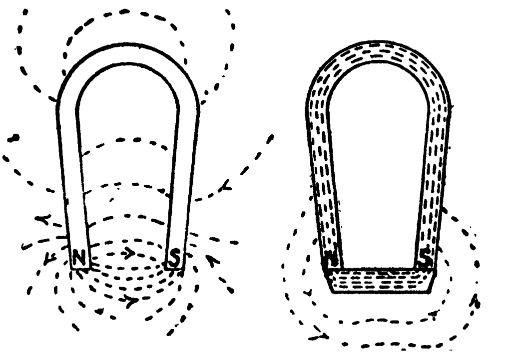


FIG. 4. MAGNETIC FIELD WITH KEEPER ACROSS POLES OF MAGNET

it. Other materials do not have any advantage over air, so a brass keeper has no effect.

The poles of a magnet are the points at which the lines of force leave the magnet for the surrounding medium and enter it again. A magnetized ring would have no poles, but if a section were cut out poles would appear at the gap, wherever the ring were cut.

Pure iron has the property of being magnetized, but does not retain its magnetism after the magnetizing force is removed. Steel, which is iron with certain other matter such as a small percentage of carbon, will retain magnetism once it has been magnetized.

If an insulated wire is wound round a bar of iron and an electric current is passed through the wire, the bar becomes a magnet and remains so only for so long

as the current is passing; if the iron bar is replaced by a steel one it also becomes a magnet but retains its magnetism after the current is cut off.

From this we may conclude that a wire carrying an electric current produces a magnetic field, and we shall be correct.

The three really important points to remember in connection with magnetism are—

1. That magnetic lines of force always take the shortest possible path between the poles and resist any attempt to lengthen them.

2. That a piece of iron placed in a magnetic field becomes a magnet for so long as the field is maintained.

3. An electric current passing through a wire creates a magnetic field round the wire.

In addition, like magnetic poles repel one another and unlike poles attract. Thus a north pole repels a north pole and attracts a south pole, and south poles repel one another and attract north poles. Also such forces of repulsion and attraction are exercised equally by both poles. That is, there is just as much tendency for the magnet to move to the iron keeper as for the keeper to move to the magnet.

The strength of the magnetic field is represented by the number of magnetic lines supposed to pass through a unit area.

In these days of the almost universal use of wireless reception there is a fairly general knowledge of electricity, and the simple measurement of currents and voltages. It is important for the study of the generation and transmission of power to have a right conception of the simpler units adopted for electrical measurements.

The most important are the volt, ampere, and ohm. The volt, sometimes called E.M.F. (electromotive force) or potential, is the unit of electrical pressure and is analogous to the temperature as measured by the

thermometer in heat, or the pressure in a steam boiler measured in pounds per square inch. A voltage can exist across two terminals whether or not a current is flowing from them. When dealing with heat we measure the temperature above or below an arbitrary zero. Steam pressure is measured against atmospheric pressure, but electrical voltage is measured against the point to which a current, if allowed to flow from the positive or high point, will return.

We measure the potential energy of a head of water above a waterfall from the bottom of the fall to the top, irrespective as to whether the bottom of the fall is at sea-level or not, although heights are usually measured from sea-level to which the water will ultimately return. In an electricity supply circuit one point is usually connected to earth, which corresponds in the water measurement referred to, i.e. sea-level.

As you know, sometimes you have an electricity supply to a works at a pressure of 440 volts for power and 220 volts for lighting.

When this is the case, one line is 220 volts above earth and the other 220 volts below earth. A voltmeter (the instrument for measuring voltage), having + and – terminals, will read 220 volts if the + terminal is connected to the line at the pressure above earth and the – terminal to the earthed line. It will also read 220 volts if the + terminal is connected to the earthed line and the – terminal connected to the line at the pressure below earth.

Between the line above earth and the line below earth it will read 440 volts.

Think of the thermometer scale: degrees above zero are positive, +, degrees below zero are negative, –; 220° above zero is + 220°, usually written 220°; 220° below zero is – 220°, always written – 220°.

The difference in temperature between zero and + 220° is 220°, between zero and – 220° is 220°, therefore

the difference in temperature between $-220°$ and $+220°$ is $440°$.

Just as the rate of flow of heat between two points depends on the difference of temperature between those two points and the conductivity of the material connecting the points, so the rate of flow of electricity depends on the difference of pressure between two points, i.e. the voltage, and the resistance offered by, or the conductivity of the material connecting the points. The voltage, therefore, is the measurement of the difference of electrical pressure between two points.

The ampere, commonly contracted to amp., is the unit of the rate of flow of electrical current.

The popular conception of the ampere is that it represents a quantity of electricity. This is wrong; it can be used in conjunction with time to represent a quantity, but alone, such a figure as 20 amp. represents no more than the expression 20 gallons per minute. Twenty gallons per minute for 2 min. represents the quantity of 40 gal. Twenty amperes for 2 sec. represents a quantity of electricity of 120 coulombs. The coulomb is the unit of electrical quantity. This term and measurement are used only by scientists, and it will not be mentioned again. It is possible, however, that the popular misconception of the ampere has arisen from the practice of describing batteries and accumulators as being of so much ampere-hour capacity, which simply means that the capacity of the battery is such that a 20 amp.-hour battery will allow current to be taken from it at the rate of 20 amp. for 1 hour, 10 amp. for 2 hours, 5 amp. for 4 hours, or 1 amp. for 20 hours, and so forth, before reaching the point at which it is discharged.

The *cusec* is a unit sometimes used in connection with the rate of flow of water, and is the corresponding equivalent of the ampere. One cusec means 1 cubic

foot per second, and so the product of the rate of flow in cusecs and the time in seconds gives the quantity that has passed in cubic feet. Thus, if water flows at the rate of 5 cusecs the amount of water that passes in 2 min. is $5 \times 120 = 600$ cub. ft. The term is not very well known and is usually replaced by cubic feet per second. Also the unit is rather large for many purposes.

To obtain a proper conception of the volt and ampere is not easy, but the ohm is much simpler.

The ohm is the measurement of the resistance offered to the passage of an electric current.

Assuming that you wish to pass in a certain time a given quantity of water through a pipe from one point to another, both points being at the same level. A small pipe would offer more resistance to the passage of the water than a large one. As the time and quantity of water to be passed are both fixed the rate of flow will be constant. For example, if 100 gal. is to be passed in half an hour, the rate of flow (corresponding to amperes) will be 200 gal. per hour, the pressure necessary to pass the water (corresponding to volts) will depend on the resistance offered by the pipe (corresponding to ohms) which will depend on the size of its bore, its straightness, the length of the pipe, and the smoothness of the inside. The resistance offered to the passage of an electrical current depends generally on the size of the conductor (sectional area), the material from which it is made, and its length; sometimes there are additional factors.

The electrical units are fixed so that a pressure of 1 volt will cause current to flow at the rate of 1 amp. through a resistance of 1 ohm. This may be expressed—

$$\text{Current (amp.)} = \frac{\text{pressure (volts)}}{\text{resistance (ohms)}}$$

The symbols used for these units are usually current I; volts E; and resistance R.

The formula then becomes $I = \frac{E}{R}$, which means that in any electrical conductor of a given resistance (measured in ohms) the rate of flow of the current (measured in amperes) is directly proportional to the difference of electrical pressure (measured in volts) across its ends.

Having the formula $I = \frac{E}{R}$

We know that $E = RI$

and $R = \frac{E}{I}$

Therefore, being given the value of two of the symbols we can always find the third.

This expression represents **Ohm's Law** and is the most important and fundamental formula used in electrical engineering; its applications are so frequent that it must be committed to memory.

In order to assist in this we will work out a few examples.

An electric lamp on a 200-volt circuit takes a current of $\frac{1}{2}$ amp. What is its resistance?

$$I = \frac{E}{R} \quad \therefore \quad R = \frac{E}{I}$$

Substituting

$$\text{Resistance of lamp} = \frac{200}{\frac{1}{2}} = 400 \text{ ohms.}$$

To keep an electric fire red hot requires a current of 2 amp.; its resistance is 120 ohm.

What is the voltage of the supply on which it should be used?

$$E = RI$$

Substituting

$$\text{Voltage of supply} = 120 \times 2 = 240 \text{ volts}$$

What current is passed by a resistance of 500 ohms on a 100-volt circuit?

$$I = \frac{E}{R}$$

Substituting

$$\text{Current} = \frac{100}{500} = \frac{1}{5} \text{ or } 0{\cdot}2 \text{ amp.}$$

Power is the rate at which work is done.

The power in an electrical circuit is equal to the rate of flow of the current multiplied by the pressure across the ends of the circuit in volts.

$$\text{Power} = \text{current} \times \text{volts}$$

Power is expressed in watts W

$$1 \text{ watt} = 1 \text{ amp.} \times 1 \text{ volt}$$

We therefore have the next useful equation

$$W = I \times E$$

From this we obtain

$$I = \frac{W}{E} \text{ and } E = \frac{W}{I}$$

For example, what current does a 60-watt lamp take on a 240-volt circuit?

$$I = \frac{W}{E}, \quad I = \frac{60}{240} = \frac{1}{4} \text{ amp.}$$

The watt is too small a unit for the measurement of the power required for driving motors and heavy loads. Consequently, the kilowatt = 1,000 watts is more commonly used, particularly to express heavy loads.

To measure the electricity supply in order that a charge can be made for it, in addition to the power, it is necessary to know the length of time for which it is used. A suitable unit is made for this purpose by

multiplying the power by the time. This unit is the kilowatt-hour, and 1 kWh is known as a Board of Trade Unit or B.T.U. This must not be confused with the British Thermal Unit, also sometimes contracted to B.T.U., although it is now usually written B.Th.U. which has the advantage of avoiding such confusion.

There is one other formula in common use. We have watts expressed in terms of volts and amperes; they can therefore be found in terms of amperes and ohms

We know that $W = E \times I$

and that $E = R \times I$

In the equation $W = E \times I$

we can therefore substitute

$R \times I$ for E, resulting in

$$W = R \times I \times I$$

usually written

$$W = I^2R$$

$$\text{(watts)} = \text{(current)}^2 \times \text{resistance.}$$

As with heat the electrical conductivity, usually for electrical purposes expressed as resistance (the inverse of conductivity), varies for different materials.

The metals and carbon are all fairly good conductors; the non-metallic substances are usually in a varying degree insulators. There is no hard and fast line drawn between conductors and insulators, which all conduct electricity to a certain extent. Insulators are really very poor conductors.

Water is neither a good conductor nor insulator.

A trace of impurity in water, particularly if acid or alkaline, will very much increase its conducting properties. Dry air is an excellent insulator, but damp air, on account of the water which it contains, becomes a conductor.

Copper is not the best conductor, but on account of first cost it is the most economical to use.

Aluminium will compare quite well from the point of view of cost, but has other disadvantages; for the same carrying capacity the wire is larger, consequently the cable is more bulky, and owing to the difficulty of soldering aluminium, jointing is a troublesome matter.

Cables for carrying current consist of a core, usually of stranded copper wire. For overhead work the air will act as an insulator except at the points of support where porcelain or some equivalent is placed between the core and earth connected metal.

If the cable is to be run in pipes, underground, or in positions where it might be touched by animals, the core is covered throughout its length by insulating materials, and sometimes, for mechanical protection, outside this is a layer of steel or lead.

There is no such thing as a perfect conductor, that is, something which will carry electricity without loss.

Wherever there is resistance, and it is found in all conductors, to the passage of the current, heat is generated when current flows, and this heat represents the principal loss in transmission.

In a lightly loaded conductor the heat is scarcely perceptible, but if electricity is forced through a small wire of high resistance material, so much heat is generated that it is accompanied by light. This is the principle of the electric lamp. Practically all the energy used in the electric lamp is dissipated in heat, only a very small proportion appearing as light. Up to the present the commercial production of light, unaccompanied by heat, has baffled scientists; when this problem is solved there will be a considerable saving in our lighting bills.

One effect of the electric current, then, is to produce heat in the conductor which carries it.

The second effect is the production of magnetism round the conductor.

If a current-carrying wire is wound up in the form of a spiral, it will be found to have a magnetic field and to behave as a steel magnet.

A piece of iron or steel placed in the spiral becomes magnetized.

An electric current has chemical effects as, if passed through certain liquids and gases which are compounds, it splits them up into their constituent elements. This process is used for the production and purification of some elements, and is the basis of electro-plating.

The principle of the current causing a chemical change, and the converse chemical change producing an electric current, has enabled electrical accumulators to be produced.

In the accumulator the passage of a current, known as charging, produces chemical changes which remain until the terminals are connected to an electrical circuit enabling current to flow from the accumulator, when the chemical changes are reversed, the current flowing until the accumulator returns to the state in which it was before it was charged; when this point is reached the current ceases to flow.

The difference in pressure or the voltage across the terminals of a lead accumulator when fully charged is about 2·2 volts per cell. For practical purposes this is taken as 2 volts.

Accumulators can be connected in series or parallel; if in series the total voltage of all the cells together is the number of cells multiplied by two, and the capacity in ampere hours the same as the capacity for one cell.

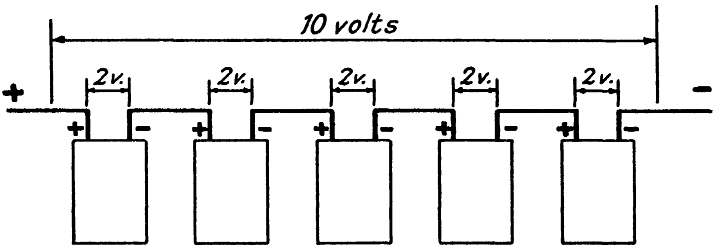
If in parallel the voltage is the voltage of one cell only and the capacity the number of cells multiplied by the capacity of one cell.

The diagram, Fig. 5, shows cells in both parallel

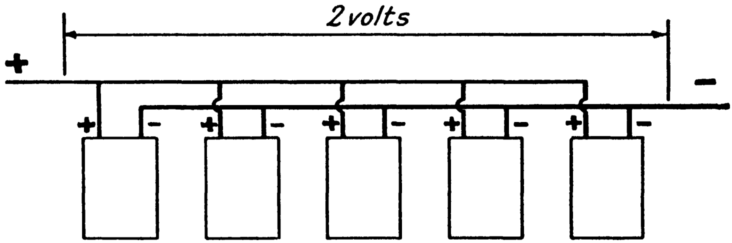
and series, and assuming 20 amp.-hr. cells are used, the voltage of 5 cells in series will be $5 \times 2 = 10$ volts.

Capacity, 20 amp.-hr.

The voltage of 5 cells in parallel will be 2.



Cells in Series



Cells in Parallel

FIG. 5

The capacity $5 \times 20 = 100$ amp.-hr.

Any number of cells connected together by either method is known as a battery.

Primary cells, often used for electric bell ringing and similar work, are made up from chemicals which are always in such a state of potential change that it is only necessary to connect a wire across the terminals and the chemical action starts at once causing a current to flow through the wire until the active materials in the cell have altered to such a condition that no further change can take place. Such cells cannot

usually be recharged by passing a current: the chemicals themselves must be renewed.

We have, up to this point, been dealing with direct current only. Alternating current is taken later on in conjunction with electrical generators.

Summary of Chapter III

A magnet is surrounded by a field of force called the magnetic field.

If the two poles of a magnet are close together the magnetic field is concentrated between the poles.

The strength of a magnetic field is indicated at any point by the density of the magnetic lines at that point.

Magnetic lines always take the shortest path, and if diverted tend to return to that path.

Iron and some of its alloys are the only materials which are magnetic to such an extent that they can be commercially used as magnets.

Pure iron can become a magnet only for so long as it is under the influence of another magnet or an electric current.

Steel retains its magnetism after the magnetizing force is removed.

The electrical unit of pressure is the Volt.

The electrical unit of rate of flow of current is the Ampere.

The electrical unit of resistance to flow of current is the Ohm.

The rate of flow of current between two points depends on the difference of pressures between the points and the resistance offered by the conductor through which the current flows—

$$I = \frac{E}{R}$$

The power in an electrical current equals the pressure multiplied by the rate of flow of the current, and is expressed in Watts—

$$W = E \times I$$

The electrical unit for measuring the energy supplied is power multiplied by time: the unit of power being the kilowatt. One B.O.T. unit or B.T.U. equals the power of 1 kW for one hour.

The losses from an electrical current passing through a wire are proportional to its resistance, and the square of the current, and are shown in heat.

A current passing through a liquid or gas may split it up into its constituent elements or cause other chemical changes.

CHAPTER IV

FURNACES

HAVING studied the elementary science necessary for a general understanding of power generation and transmission, we can turn to the production of power.

Energy is never destroyed: it may change its form and be stored up, but it always remains to be used again.

If a moving vehicle is brought to a standstill by means of a brake, the energy is dissipated mostly in heat, which still remains somewhere; at first it heats the brake parts, these in turn pass the heat on to the surrounding air raising in a very small degree the surrounding temperature.

If energy is used to pump water from a lower to a higher level, the energy is stored as potential energy in the water due to its level, and can be given up if the water is allowed to fall and drive a turbine. If the water falls by simply dropping from a height, the energy will not be gone, but will be given out in the form of heat, raising the temperature of the water and doing work by wearing away the rocks and bed of the stream, movements of air, noise, and generating electricity by friction. All this energy is uncontrolled and consequently lost.

The energy in the form of heat which we receive from the sun is stored up among other ways by causing plants to grow and chemical changes to take place, and thus fuel is produced.

The carbon in the fuel under proper conditions will combine with the oxygen in the air and the energy is given out in the form of heat which can be transformed as we have seen into mechanical energy.

This principle is called the *conservation of energy*,

i.e. energy may be dissipated uselessly but is never destroyed. We could say that a complete energy account would always balance.

In the generation of power by means of a steam plant, the latent energy stored up in the coal or oil fuel is converted by chemical action into heat. The heat energy acts on the water in the boiler changing its state into that of steam, consequently increasing its volume and setting up a mechanical force, which force, being allowed to operate on a body capable of movement, produces motion through space, which, in its turn, is allowed to carry out the required work.

The process of generating heat slowly, as, for instance, to boil water in a boiler, is known as burning fuel, and is one form of combustion. If the combustion of the fuel with the oxygen of the air takes place almost instantaneously, the process is known as explosion.

If a mixture of petrol vapour or coal gas with air is heated to such a point that explosion takes place, the chemical action is the same as in burning, but the heat generated and the volume of hot gas produced by the explosion causes such a tremendous increase in pressure that the force of the explosion can be applied directly to a body and produce mechanical energy.

The first example of slow burning is the ordinary steam plant. The second, the gas plant and internal combustion engine.

The energy of wind or falling water can be applied directly to a body capable of movement, and power produced; the former is met with only for small powers, but where falling water is available, considerable energy is utilized in this way.

Steam plant will be considered first, the fuel available being generally either coal or oil.

Coal, as we know, is a black solid substance consisting of a little pure carbon mixed with a proportion of

other matter, usually carbons in chemical combination with hydrogen, called hydrocarbons.

At a gas works coal is heated in a retort; coal gas is distilled off and passed through pipes for domestic and other supply, and practically pure carbon in the form of coke is left in the retort. There are various impurities, some useful as by-products, but roughly the process is as above.

Coal is really, therefore, a mixture of two fuels, pure carbon and hydrocarbons (chemical combinations of carbon and hydrogen). Both the pure carbon and the hydrocarbons will burn if mixed with air which contains the necessary oxygen and raised to a sufficiently high temperature.

When the carbon burns in a plentiful supply of air, the combination of the carbon and oxygen forms a gas known as carbon dioxide, carbonic acid gas, or by its chemical formula CO_2. The carbon which is in combination with the hydrogen, also forms CO_2 with the oxygen, and the hydrogen forms water (H_2O) by combining with oxygen.

The combustion of coal takes place in a furnace under a boiler of some form.

The design of the furnace is important, as to obtain the maximum theoretical efficiency, all the carbon must be burnt, and all the heat transferred to the water.

Black smoke consists of particles of unburnt carbon resulting from imperfect combustion, and the warmth which you feel when near a furnace is waste heat which, if possible, should have been used for heating the water. These two losses are only the beginning of a whole series of inefficiencies which are found when using steam plant for the transformation of the energy in coal.

An insufficient supply of air produces visible loss in the form of unburnt carbon escaping from the chimney in the form of black smoke; in addition, it

allows invisible unburnt hot gases to escape. Too low a temperature in a furnace will also result in incomplete combustion. This can easily be realized from the example of a low fire burning in an ordinary household grate.

You have probably noticed that if the fire is low and fresh coal is added, before very long yellowish smoke will be given off and pass up the chimney; some lighted paper put in this smoke will cause it to burn, but the flame goes out as soon as or soon after the paper is taken away. This yellow smoke is the volatile matter in the coal which is distilled off by the heat of the fire but not burnt, as the temperature above the fire is too low to support combustion.

Let us see what takes place in a furnace when coal is added to the fire.

The furnace is already hot and the first effect is a volume of flame caused by the burning of the volatile hydrocarbons driven off by the heat of the existing fire. The flames are diverted by means of baffles to the tubes or other points at which they can most efficiently heat the water.

The residue in the fire after the gases are expelled is practically pure carbon and ash.

The incandescent mass of carbon on the firebars has a certain thickness, and air is being drawn through it by the draught of the chimney.

The only part of the air which is useful for combustion is the oxygen. Carbon combines with oxygen in two ways, forming either one or both of two gases, having quite different properties.

In an excess of oxygen the carbon, when burnt, forms carbon dioxide, sometimes called carbonic acid gas, usually indicated by the chemical formula CO_2, which means that in one molecule of the gas there are two atoms of oxygen to one of carbon.

Under other circumstances, particularly if the supply

of oxygen is insufficient, the carbon will combine to form carbon monoxide, chemical formula CO, indicating that in one molecule of the gas there is only one atom of oxygen combined with one of carbon.

Carbon monoxide can also be formed if carbon dioxide passes over red-hot carbon, the hot carbon having such an affinity for oxygen that it will take away one of the atoms of oxygen from CO_2, leaving CO and forming more CO with the oxygen atom which it has taken.

Carbon dioxide (CO_2) is a colourless inert gas; it will not burn, it is non-poisonous, and will not support life or combustion. Its properties are mainly negative.

On the other hand, carbon monoxide (CO), is a gas which in the presence of oxygen burns readily, forming CO_2; it is very poisonous and quite colourless.

You have probably seen blue flames burning over a coke or clear coal fire. These are flames of CO formed from oxygen and CO_2 passing through the fire and burning in the extra oxygen available in the air above the fire.

Returning to the boiler furnace, we have seen how the volatile part of the coal is consumed, leaving a red-hot or incandescent bed of carbon.

Air passes through this bed from below. The nitrogen in the air passes through unchanged chemically, but the oxygen, when it meets the glowing carbon, unites chemically with it, forming CO_2; as the CO_2 passes further through the fire bed, and unless the fire is very thin or oxygen very much in excess, a part of it will be changed as previously described to CO. The CO_2 which passes through unchanged represents complete combustion and efficiency, and can be allowed to pass away up the chimney, but the CO must be burnt above the fire to CO_2 for which purpose more air must be supplied at the top of the fire.

The heat of the fire usually has to do the work of

drawing the air over and through the furnace and carrying the waste gases up the chimney. Further, air consisting of a mixture of oxygen and nitrogen in the proportion of 23 parts of oxygen to 77 of nitrogen, and the oxygen being the only part which is useful, great quantities of nitrogen, which is useless, have to be drawn through the furnace and carried up the chimney simply to use the oxygen with which it is mixed. There is, therefore, considerable loss in both heating up and moving this useless gas.

The value of any particular coal as a fuel can be tested by the chemist. Roughly, coal may be divided into two classes, anthracite and bituminous.

Anthracite coal is nearly pure carbon and contains very little volatile matter, and as the black smoke from a chimney is mostly carbon in fine particles left over by the incomplete combustion of the volatile gases from the coal, anthracite is practically smokeless. A furnace designed for burning bituminous coal would not be efficient for anthracite owing to its not being necessary to provide for the consumption of the hydrocarbon cases, absent when anthracite is used.

Bituminous coals vary very much in the proportion of carbon to volatile matter; with some it is almost impossible to prevent black smoke, but with others, such as Welsh steam coal, there is little smoke, and the hydrocarbon gases burn with a very hot flame, which is excellent for steam raising.

A good coal will be rich in carbon and hydrocarbons, low in moisture and ash.

The oil fuel burnt under boilers is found in natural deposits in the earth.

The crude oil is heated, and at a low temperature the petrol distils over; as the temperature is raised paraffin comes over and finally a sticky oily mass, not volatile at medium temperatures, is left. This is known as fuel oil, and consists of liquid hydrocarbons.

The crude oil is sprayed into the furnace under a high pressure. The finely divided spray mixed with the oxygen of the air will vaporize with the heat of the furnace and burn just as hydrocarbon gases over a coal fire. The efficiency is measured by the proportion of CO_2 in the flue gases.

You will probably have gathered that furnaces are very inefficient; even when perfectly managed, heat is lost in tremendous quantities, and what is really more important is that however well a furnace is designed, its efficiency in working is controlled by the quality of the labour employed for firing.

A good fireman will produce a far better efficiency from a poorly designed furnace than a bad fireman from the best furnace obtainable, and in spite of all sorts of mechanical devices the best hand firing cannot be beaten, but such labour is not always obtainable.

One of the most important points to watch in the generation of power by steam is the method of firing. Mechanical stokers can be used, and with certain grades of fuel and water-tube boilers, with a fairly constant load, they are certainly as efficient as, if not more so, than the best hand firing, but with narrow-flued boilers they are not so useful.

A fireman can generally put on about 50 tons of coal per week; very often this figure is exceeded. Considering the value of the material which he handles and how easily it may be used inefficiently, it is a very poor economy to employ cheap labour for firing furnaces under boilers.

Firing includes the general control of the dampers and means of admitting air to the furnace. The commonest form of inefficiency is the admission of too much air, both under and over the furnace.

When coal is added the furnace door must be opened: this naturally allowed a rush of cold air, reducing the general temperature above the furnace so that

part of the hydrocarbon gases will not be properly burnt. At first, too, after firing, these gases are given off in great quantities, requiring much more air than normal for their complete combustion. The result of all this is the production of black smoke, consequently the furnace door is usually left open to provide the extra air required and thus stop the smoke.

The practice is quite permissible if the door is open for only the very short time necessary, but if unduly prolonged, cold air is introduced in great quantities with the resulting inefficiency already pointed out.

Sometimes, if the design of the furnace permits, the additional air may be admitted by the fireman through the ashpit to the back of the bridge; this is probably worse as it is not so obvious and may go on for a long time unnoticed.

Either method reduces the draught through the fire and consequently its temperature.

A fire burns most quickly at the back end nearest to the chimney; consequently, unless attended to properly at this point, more air will pass through the thin portion, and the flow through the thick portion will be lessened, with again reduced furnace temperature and unused air passing up the chimney.

The same remarks apply to thin places which may appear in the fire owing to uneven spreading of the coal.

The fire must not be allowed to become too thick or sufficient air cannot pass. The way to judge the quality of a fire is by the evenness of its incandescence; thin places are always hotter than the thicker parts.

There are various ways of adding fuel. General spreading giving special attention to thin places is a common method; alternatively and better is the method of firing one side at a time, thus keeping the alternate sides in a state of incandescence, the high temperature assisting in consuming the smoke from the added fuel.

Probably, under most conditions, the coking method is the best. The fresh fuel is added always at the front of the grate and pushed towards the back as it is consumed; this means that the fire at the back is always incandescent and consequently assists in consuming smoke, and the general temperature of the furnace is kept higher. The majority of mechanical stokers work on this principle, an exception being the underfeed type, in which the coal is forced under the incandescent fire through which the volatile gases pass.

We have seen that with perfect combustion and maximum efficiency, all the carbon, both in its pure form and combined with hydrogen, must be burnt to CO_2. Enough air must be supplied for this purpose and only very little more.

This air will take through the furnace a large amount of nitrogen, which is unnecessary but cannot be avoided. The ideal flue gas would therefore be composed of CO_2, nitrogen, and water (in the form of steam) and nothing else; of course, this is impossible in practice, but it shows how the efficiency of the furnace may be measured. That is, the proportion of CO_2 in the furnace gases will vary with the efficiency of the firing. Too much air will bring the percentage of CO_2 down too much; CO will do the same. In practice, 12 to 13 per cent of CO_2 is usually considered very good. It is quite probable that the average, including the very many small plants about the country which have no means of measuring their efficiency, is round about 5 per cent or even less. This means that a terrible waste of fuel is always going on, and represents a heavy drain on industry.

To give some idea of what the CO_2 percentage means, it is interesting to note that—

10 per cent CO_2 represents 16·8 per cent of heat lost if flue gas temperature is 500° F.

6 per cent CO_2 represents 27·3 per cent of heat lost if flue gas temperature is 500° F.

There are various types of instrument for measuring the percentage of CO_2 in the flue gases; the general principle is to take a sample of the gas, extract from it the CO_2 by absorbing it in a caustic solution such as caustic potash, then from the difference in volume at constant temperature before and after extraction of the CO_2 the percentage is readily obtained. Other instruments for this purpose simply measure some physical property, such as density or heat conductivity, of the gases, and the CO_2 is estimated by this means.

These instruments can be obtained and are made automatic in their action, both for registering and recording for future inspection the variations in CO_2 percentage.

It is important at the same time to record the temperature of the flue gases, and recording thermometers are used for this purpose.

The temperatures may be taken at various points in the system, low temperatures by thermometers, and high temperatures by means of the pyrometer.

Flue gases should leave the furnace at about 600° F.; if under 450° F. the draught will suffer.

We have so far assumed that the air is moved through the fire by the natural draught of the chimney. Sometimes a sufficiently high chimney is not possible or desirable. An instance of the former is in the steam locomotive, where it would be quite impossible to have a chimney capable of producing enough draught to pass air through the fire in sufficient quantities.

Stephenson overcame this by turning the exhaust steam from the cylinders up the chimney, the blast of this steam from the nozzle in the chimney sucking the air through the furnace. This practice has been continued on locomotives until the present day.

In stationary plants, without a high chimney, two methods of providing the necessary air are available, viz. forced and induced draught.

In the earlier designs for forced draught the furnace was completely closed and air supplied under pressure by means of fans. The present most popular method is the Meldrum system in which two blowers, shaped like long trumpets, are placed on the front plate of the ash-pit, the smaller end being fixed to the plate. This system may become very wasteful of steam unless constant attention is paid to the steam jets.

In the centre of each, at the small end, is a jet supplied with steam under pressure. This jet of steam carries with it on the injector principle a large quantity of air which is thus delivered under pressure to the fire.

The induced draught system is not so common. A large fan is provided which will carry all the flue gases and through which they pass after leaving the furnace, the fan being revolved by mechanical means.

The difference in pressure caused by the suction of this fan draws the air through the fire.

Just the same, or even more, care must be taken to keep the fire at its highest efficiency when induced or forced draught is used.

The best stoker is not he who burns the most or the least coal, but the one who produces the maximum of steam for the minimum of fuel.

The possible avoidable inefficiencies which may occur in a furnace may be summarized as follows—

1. Bad firing; resulting in too much air through the furnace, with consequent loss of heat from cold air absorbing heat and carrying it up the chimney. Too much air above the fire means bad draught through the fire and a cool fire; not enough air results in incomplete combustion.

2. Careless maintenance; resulting in unrepaired

cracks and holes in the brickwork with consequent air leakages, reducing draught, etc.

3. Improper, or absence of, lagging with heat insulating material at all points where heat may escape.

4. Deposits of soot interfering with the transfer of heat.

The unavoidable losses are—

1. Heat used to produce circulation of air through the furnace.
2. Heat lost by radiation from furnace walls, etc.
3. Heat used in moving large quantities of nitrogen through the flue and up the chimney.
4. Heat used in raising the temperature of the nitrogen.
5. Heat lost in hot ashes.
6. Unburnt fuel in ashes.

Some of the heat in the unavoidable losses can be recovered, as will be seen later, and it should be noted that if heat is not used directly to produce draught, i.e. by means of a high chimney, mechanical power will be required for that purpose, which must be generated primarily from the fuel and pass through the form of heat.

In modern practice the furnace is always designed in conjunction with the boiler. The function of the furnace is to convert the potential heat of the coal and transfer it to the water in the boiler.

Heat flows from a hot body to a cooler body, and the transference of heat depends upon the difference in temperature between the two bodies and the contact between them. Consequently, the furnace temperature should be as high as possible, and the maximum area of contact must be provided between the fire and hot gases, and the boiler.

Before passing on to the consideration of boilers it would be well to note that the consumption of coal in furnaces is measured by the number of pounds per hour

burned per square foot of the area of the grate. Thus, if the grate area of a furnace is 32 sq. ft. and 5,040 lb. of fuel are burnt in 10 hr., the consumption would be

$$\frac{5040}{32 \times 10} = 15{\cdot}75 \text{ lb. per square foot per hour.}$$

Summary of Chapter IV

Energy is never lost: it may change its form.

Potential energy in water stored at a height is available for power supply.

Potential energy stored in coal or other fuel is the usual source of power.

Fuel subjected to a high temperature burns combining with the oxygen of the air, the combustion giving out heat which is utilized to boil water and produce steam under pressure.

Air consists of a mixture of Oxygen and Nitrogen.

Coal consists of a mixture of pure Carbon, volatile Hydrocarbons (chemical combinations of Hydrogen and Carbon) and incombustible ash.

Carbon and Hydrocarbons burn with Oxygen to form CO_2 (Carbon Dioxide) and Steam (H_2O).

Maximum efficiency in a furnace means all combustible parts of the fuel burnt to CO_2 and little excess of air. Insufficient air produces black smoke—unburnt carbon. Too much air lowering the furnace temperature may also cause black smoke.

Combustion requires oxygen only; to obtain the necessary oxygen from the air large quantities of nitrogen, although useless, must be taken through the fire and up the chimney. Power is unavoidably wasted heating and moving this nitrogen.

The efficient combustion of the fuel is entirely under the control of the fireman. A good fireman with a badly designed boiler can obtain better results than a poor fireman with a good boiler.

The efficiency of a furnace may be measured by the percentage of CO_2 in the flue gases. Thirteen per cent is a good figure when coal is the fuel. With oil fuel it will be lower owing to the hydrogen being greater.

The CO_2 percentage must be taken in conjunction with the temperature of the gases leaving the boiler; 500° to 600° F. is a usual figure.

Draught through the fire may be produced by a high chimney, pressure, or suction.

Pressure is produced by steam jets (Meldrum system) or by fan (Howden system).

Suction is induced by a mechanically driven fan.

Losses in a furnace are due to—

1. Bad firing (including control of draught).
2. Careless maintenance.
3. Improper, or absence of, lagging.

Coal consumption can be expressed as coal per square foot of grate area per hour.

CHAPTER V

BOILERS

THE boiler of a steam plant is the container placed over or used in conjunction with the furnace. It holds the water which it is required to convert into steam.

As we have already seen, heat must be supplied to the water to convert it into steam, and in order to transfer the heat quickly and efficiently the area of contact between the furnace and the water, *via* the boiler plates, must be as great as possible, and the difference of temperature between the two must be also a maximum.

At a pressure of 200 lb. per sq. in. (abs.) water boils at about 380° F., therefore if working at this pressure, furnace gases at any lower temperature than 380° F. in contact with the boiler will extract heat; there is therefore no point in making the area so large that there is a possibility of the gases taking up this heat, and even if they are hotter than the water there must be a considerable difference in the temperatures for any reasonable quantity of heat to be transferred. We shall see later that arrangements can be made whereby the water first entering the boiler and, consequently, below boiling point meets the partially cooled gases and can extract some of this otherwise waste heat.

The remaining important factor governing the design of the boiler is the necessity for a form of construction to stand the high internal pressure of the steam.

An ideal shape to stand such pressure is a sphere, but difficulties in construction apart from such considerations as convenience for the transfer of heat, make a spherical shape impossible commercially.

A compromise, therefore, has to be made, and the

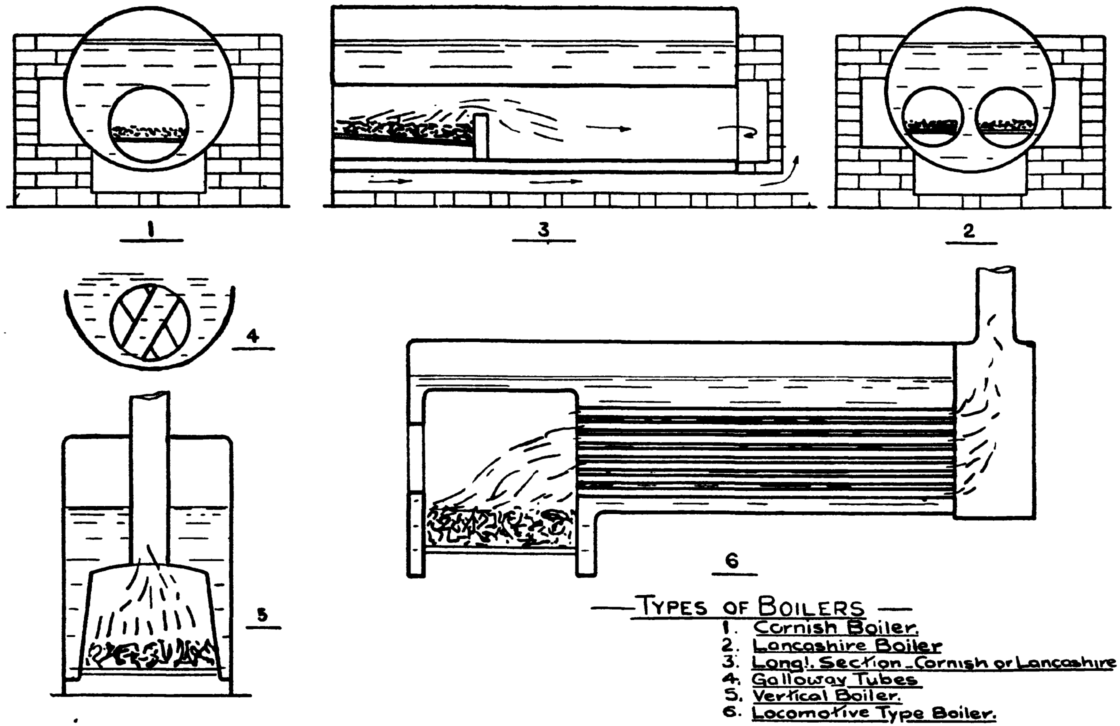


FIG. 6. TYPES OF STEAM BOILERS

next best, viz. a cylinder, is chosen, and it will be found that practically all boilers are built up from parts which are cylindrical in form.

The earliest commercial form of boiler for pressures over a few pounds per square inch was the Cornish boiler introduced by Trevithick about 1800, and this type is still in fairly common use.

The Cornish boiler is shown diagrammatically at No. 1, Fig. 6. It consists of an outer cylindrical shell through which passes a smaller cylinder containing the furnace. The front of the furnace is closed by the usual door, and the back is open to the flues which are built in the brickwork on which the boiler is set. The path of the hot gases is shown by the arrows, the air enters at the front of the furnace passing through the fire, out at the back, along the sides outside the boiler to the front again, then underneath and up the chimney.

The Lancashire boiler, in more common use still, is similar, but provided with two smaller parallel cylinders through the outer shell, each of these constituting a separate furnace; the flues are arranged as in a Cornish boiler.

To assist in heating the water, both Cornish and Lancashire boilers are frequently fitted with tubes across the furnace space and behind the fire. These tubes carry water through the hot gases and assist in circulation; they are known as Galloway tubes, and illustrated at No. 4, Fig. 6.

The great trouble with boilers is the formation of scale, the incrustation which deposits on the inside of the boiler from the evaporation of hard or impure water.

The steel plate from which the boiler is made is only kept from becoming red hot or even melting by the action of the water extracting its heat; if, therefore, the deposition of scale, which is a bad heat conductor, is sufficient to stop or even impede this cooling action

of the water, there is great danger of a burst; apart from deposited scale, there is always the possibility of sediment, which may be either sand, other insoluble impurities in the water, or loose scale filling some pocket and producing a like result.

One great advantage of the Cornish and Lancashire boilers is that sediment falls to the bottom where it rests on plate which is not in contact with the hottest part of the furnace, the flue gases passing underneath not being sufficiently hot to cause damage.

Oil in the water prevents the water making good contact with the boiler plate; it may also cause corrosion and pitting, particularly at the water level, and organic matter or carbonate of soda in large amounts will cause frothing with consequent priming. A boiler is said to prime when considerable quantities of water pass over with the steam.

If the engine is non-condensing, the greatest trouble will be from various forms of hardness. If the exhaust steam is condensed and returned to the boiler, oil which it picks up on its passage through the engine must be extracted, otherwise there is danger from corrosion or priming from saponification of the oil, but the deposition due to hardness is very considerably reduced.

Water softening plant and proper filtration will do much to reduce scale, but a boiler must be cleaned out and examined at least once a year, and much more frequently if it is subjected to heavy duty.

The small vertical boiler No. 5 (Fig. 6), often seen with an engine forming a complete portable unit, is of quite simple construction; it consists of a vertical cylinder containing a smaller cylinder, which extends upwards for about half the height of the outer cylinder, and forms a fire-box. The chimney from this fire-box passes right through and is extended above the top of the boiler. Sometimes, for quick steaming, the part

of the chimney passing through the boiler is split up into a number of smaller tubes which join a smoke-box at the top, the single chimney being extended from the smoke-box and the external appearance remaining the same.

This small type of boiler leads at once to the locomotive type No. 6 (Fig. 6), as it resembles very much the small boiler with tubes, placed on its side.

The locomotive type of boiler, as the name implies, is used mainly on steam locomotives, but it is also frequently seen on portable, semi-portable, or even fixed units, the engine being housed below the boiler in front of the fire-box.

The general appearance of a locomotive boiler is familiar to everybody. It is of cylindrical construction, the two ends of the cylinder being closed by means of plates. Set in one end is a furnace of rectangular shape known as the fire-box, and a cylindrical chamber at the other end which communicates with the chimney and is called the smoke-box. The water passes round the top and sides of the fire-box, and the hot gases pass from the fire-box to the smoke-box through a large number of tubes usually about 2 in. in diameter, these tubes being expanded at their ends to fit tightly into holes provided in the two end plates. The great advantage of this type of boiler is the very large heating surface, consequently extra steam can be raised quickly, and for short periods it may be forced very hard.

The water-tube boiler is the remaining type which is commonly used. There are two types, the large tube boiler and the small tube boiler. The large tube type is better for a fairly steady load, the small tube type, owing to its greater heating surface, being more useful when it is necessary to raise more steam quickly or force it to meet a special emergency.

A typical water-tube boiler made by Babcock &

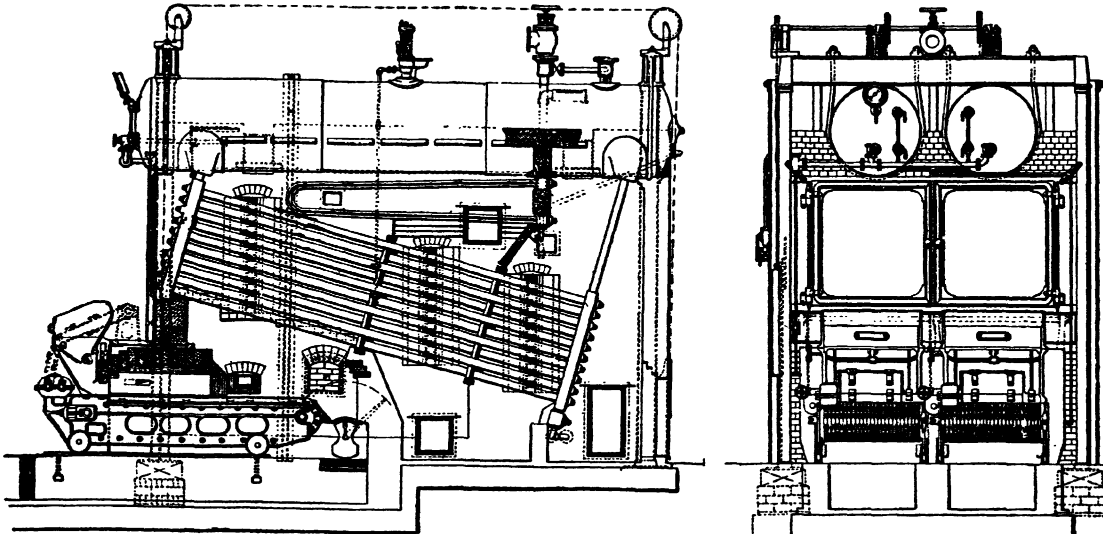


Fig. 7. Babcock and Wilcox Water-tube Boiler

Wilcox, Ltd., is shown in Fig. 7; it consists of two similar units. At the top of each is the cylindrical drum which contains the steam and water; below and in the furnace are the inclined water tubes.

Its action is as follows: The cool water, owing to its greater density, falls at the back, and is first met by the hot gases (already partially cooled) as they escape to the chimney. As the water is heated it rises up the inclined tubes, gradually increasing its temperature and at the same time meeting hotter gases until it arrives at the hottest part of the furnace and passes again to the drum as a mixture of water and steam; separation takes place, and the water continues to circulate as before.

This circulation takes place very rapidly, and by its scouring action prevents, to a great extent, the deposition of scale in the tubes. A round drum is provided at the lowest and, consequently, coolest point of the inclined water tubes, in which the solid matter settles, whence it can be readily blown off.

Water-tube boilers consist of a number of small parts with many joints, and for this reason are more liable to accident than the Lancashire type; at the same time, owing to the smallness of the tubes, should a leak or burst occur, it is not so serious a matter.

When space is limited the water-tube type should certainly be installed, as for the same steam production it is much smaller in size.

Another advantage of the water-tube boiler is that the design of the furnace is not so limited; as we have seen, the water circulation can be arranged to take advantage of the varying heat of the flue gases, whereas in the Lancashire boiler, owing to the furnace being practically water-jacketed throughout, it is kept cool at points where a maximum heat is required, and consequently is rather prone to incomplete combustion.

The large tube type of water-tube boiler can take satisfactorily a low grade of fuel; the Lancashire type requires a high grade. Fine dusty fuel can be consumed in the vertical type of boiler.

Again, the interior of the furnace for the water-tube type can be lined with a good refractory material, giving a long life to the furnace walls.

The water of a hot bath possesses a considerable amount of heat, and on opening the waste all the hot water runs away, taking with it the heat which has cost something to put into the water and has served very little useful purpose! If only some means could be devised to extract this heat from the water and store it until required to put into water for another bath, what a great saving could be effected and how the efficiency of the cleansing process could be improved!

Much the same waste is going on in furnaces throughout the world; hot flue gases, products of combustion, and nitrogen are being continually turned out into the air, carrying with them expensive heat units which cannot be recovered.

In a steam plant only about one-sixth of the energy in the fuel is available at the shaft of the engine; the balance has gone in lost heat and friction.

The only known method of extracting heat from a body is to place, in contact with it, a body at a lower temperature. Equal weights or volumes of different bodies will not hold the same quantity of heat. In a furnace and boiler all the air supplied has to be heated up to the temperature of combustion and all the water up to its boiling point before either becomes useful; the hot flue gases carrying waste heat can therefore be made to give up some of their heat to serve a useful purpose by heating the air or the water, or both, previous to their entry to the furnace or boiler. Heating the air has been tried commercially, but at first

was not very successful, as an enormous area of contact is necessary in order to pass the heat units to the air, which is a poor conductor of heat. In recent years better results have been obtained, and in modern plants the practice is becoming quite common.

Much better results have been obtained in heating the feed water to the boiler. Water is a better conductor of heat than air, and before entering the boiler is at a sufficiently low temperature to absorb readily heat from the hot gases as they leave the furnace, although they have already become too cool to transfer heat to the water already in the boiler. An arrangement in the flue of pipes carrying the feed water, in order that it may be treated in this way, is called an economizer.

Green's Economizer (Fig. 8) consists of a series of pipes about 4½ in. diameter by 10 ft. long, placed in a chamber which forms part of the main flue, the number of pipes depending on the size of the boiler.

The feed water is pumped through these pipes in the opposite direction to the flow of the gases, the cooler gases meeting the cooler water, and as the water becomes warmer it is brought progressively in contact with hotter gases nearer the fire.

The gases leaving the furnace may be at a temperature of about 600° F., and cooled down by passing through the economizer by about 250° F. to perhaps 350° F., this will usually raise the temperature of the feed water by 100° F. Very definite figures cannot be given as so much depends on local conditions.

The greatest influence on the use of the economizer is the draught in the chimney.

If the natural draught is poor the gases must leave the economizer at a higher temperature, and it may be impossible to install an economizer. Further, the economizer causes a certain amount of obstruction in the flue; this again will interfere with the draught.

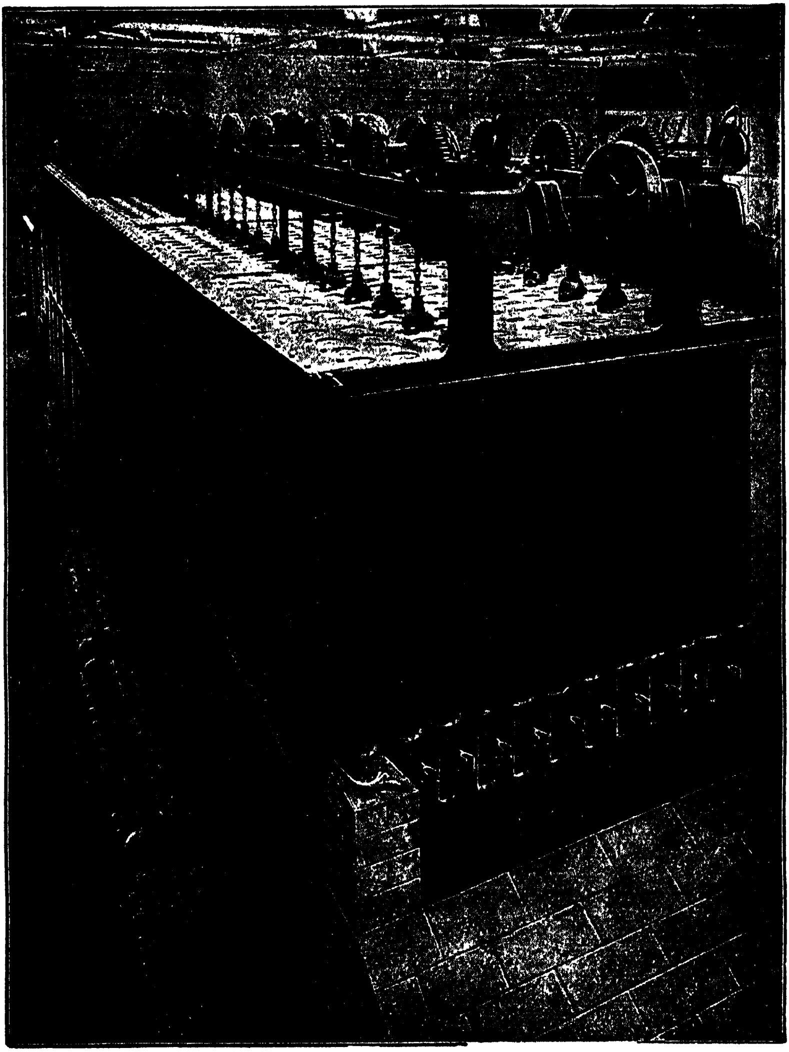


Fig. 8. General View of a Green Economizer

Arrangements are made by means of flues and dampers to divert the flue gases from the economizer, giving them a free passage to the chimney as occasion demands.

In order that heat may be absorbed to the greatest possible degree, the outside of the economizer pipes must be kept clean and free from soot. For this purpose a series of scrapers is arranged round the pipes, and these scrapers are kept in continual movement, travelling backwards and forwards from end to end of the pipes. They are driven mechanically by gearing from a moving shaft or small motor.

Water should not be supplied to an economizer at a lower temperature than about 105° F., otherwise condensation may take place on the outside of the pipes. This condensed water would then dissolve sulphur dioxide (an impurity frequently found in flue gases), and this solution has a very corrosive effect on the pipes.

Scale must be removed at regular intervals from the inside of the pipes by means of scrapers.

Small boys, who have their first boiler, obtain a great deal of joy from seeing the steam blow off at the safety valve. Later they require a boiler fitted with a water gauge, and, if possible, a pressure gauge too. All the fittings, with the addition of blow-off cocks, are essential features of the commercial boiler.

Three types of safety valve are in common use: the lever, spring-loaded, and dead-weight type. These are shown diagrammatically in Fig. 9.

In each case the pressure of the steam in the boiler acts on a valve shaped like a mushroom. This valve is held in place either by a weight acting through a lever, a spring, or a dead weight pressing directly on the valve.

Should the force of the steam pressure exceed that of the opposing weight, the valve lifts and allows steam to escape.

The water gauge consists of a heavy glass tube mounted vertically on the front of the boiler sufficiently long to cover the maximum and minimum water level. The two ends communicate through cocks with the interior of the boiler, the upper with the steam space and the lower with the water below the minimum water level.

When the cocks are open the water in the glass tube,

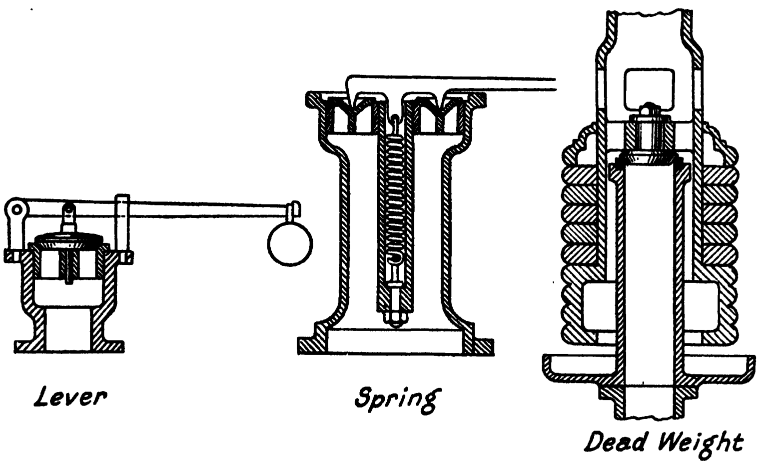


FIG. 9. TYPES OF SAFETY VALVE

which will stand at the same level as the water in the boiler, can be inspected.

The pressure gauge is interesting, the one most commonly used being the Bourdon gauge. It is used to indicate the pressure of the steam in the boiler. Most people are acquainted with those instruments of annoyance, or perhaps pleasure, which are served out at carnivals. These consist of a long flat paper tube closed at one end and provided at the other with a tubular mouthpiece. The paper tube is rolled from the closed end on itself, and is so constructed that it always tends to roll up. On blowing in through the mouthpiece the

tube tends to straighten out, the amount of straightening varying with the pressure. This illustrates the principle that a bent flattened tube closed at one end will tend to straighten if subjected to internal gas or liquid pressure.

The Bourdon gauge, illustrated in Fig. 10, consists of a flattened metal tube curved as shown, and the closed end is connected through gearing with a pointer moving over a circular dial. Steam pressure is applied from the boiler to the interior of the tube, and the movement of the closed end, which will correspond to variations in the pressure will be indicated by the pointer.

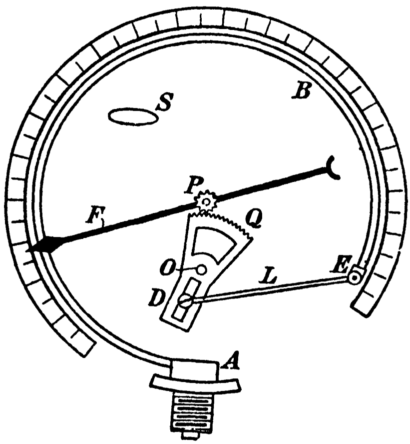


FIG. 10. BOURDON PRESSURE GAUGE

Steam pressures in the early days of boilers were very low; the tendency throughout the history of steam engineering has been steadily to increase until at present, pressures of about 200 to 300 lb. per square inch are quite usual; any possible increase in pressure means higher efficiency. Sir Charles Parsons has calculated that raising the pressure from 250 to 500 lb. per sq. in. yields a 6 per cent increase; from 250 to 1,000 lb. per sq. in., a 11 per cent increase; and from 250 to 1,500 lb. per sq. in., a 15 per cent increase in efficiency.

Boilers working at these high pressures are now made and coming into use for electricity supply stations.

The distribution of steam from the boiler takes place

through steam pipes which are covered externally by some heat-insulating compound, and is controlled by hand-operated valves. These valves are so designed that they can be opened to the full diameter of the pipe, and thus offer no obstruction to the flow of steam.

Summary of Chapter V

To transfer heat from furnace to boiler a large area of contact must be provided, and the difference of temperature between the furnace and boiler must be as great as possible.

A cylinder is the best shape of vessel, which is both convenient to manufacture and stands the maximum internal pressure for its volume. Consequently most boilers are built from parts of cylindrical shape.

The Cornish Boiler. This takes the form of a horizontal cylinder, with one cylindrical internal furnace.

The Lancashire Boiler. Similar to Cornish but provided with two furnaces, with possibly the addition of Galloway tubes.

The greatest trouble with a boiler is the deposition of scale, due to the hardness of the water, which must be removed.

Oil in the water causes corrosion, particularly at the normal water level.

If the engine is run condensing the hardness trouble is greatly reduced.

Water-softening plant reduces scale.

The Locomotive type of boiler has a large number of small tubes carrying the hot products of combustion through the boiler from fire-box to smoke-box. It is used mainly in conjunction with a steam engine, with which it is mounted to form a portable or semi-portable set.

The water-tube boiler is of two types, large tube or small tube; the water circulates through tubes in the furnace, and the steam accumulates in a cylindrical drum at the top.

Heat contained in the flue gases and otherwise wasted may be partly recovered by using the hot flue gases to heat the air supplied to the furnace or the feed water to the boiler.

Feed water heaters are called economizers.

Economizer and boiler must be kept clean externally and internally, otherwise the transfer of heat is impeded by deposits of soot or scale.

Safety valves allow steam to escape should the boiler pressure rise above a predetermined limit.

The higher the pressure at which the steam is used the greater its efficiency.

The water gauge is a glass tube fitted to the boiler front, indicating the level of the water in the boiler.

The pressure gauge indicates on a dial the pressure of the steam above atmospheric pressure.

CHAPTER VI

BOILER-HOUSE MEASURING INSTRUMENTS

It is generally found that when some new discovery in engineering is made or a new process developed commercially, that at the same time the necessary meters for its control are adapted or designed in order that the maximum efficiency may be obtained. Engineering and industrial development, as we know it at the present day, all originated in the discovery and application of steam power in the 18th century.

In those days methods were primitive, and facilities for measuring and controlling by suitable meters were not available, with the result that to a great extent their necessity has not been realized, and practice has not kept pace with the increase in scientific knowledge.

Very much the same conditions retarded, for a time, the development of special steels. The early smith would harden and temper steel by rule of thumb methods, judging temperatures by visual observation of colour.

He handed his experience on to others who, in turn, became equally skilled, and even at the present day works may be found where the heat of a furnace for treating steel is judged by eye, by someone who, although undoubtedly wonderfully skilled, must be influenced by what he had for dinner or by the state of his health. Fortunately in the case of steel manufacture and treatment, such conditions are now rare. The scientist has aided the manufacturer, and accurate measuring instruments, such as pyrometers, are now available, which make processes practically independent of the human factor, and an art has been changed into an exact science.

The present generation is concentrating its energies on increased efficiency; cost accountancy is making progress, and except in very poor organizations very careful watch is kept on material and labour in order to avoid or reduce waste.

How often do we see the same attention paid to services such as steam, gas, electricity, and water? It has become a habit to weigh, measure, or count material issued from store, but it is equally a habit to give a man a water, steam, or gas cock and let him use it or waste it at his will.

Further, if a factory makes its own power, the power house is really a separate factory and should be as efficiently controlled as any other department; yet in a huge majority of factory power houses tremendous unnecessary waste of heat obtained from expensive coal is going on all the time, unchecked and unheeded, simply because, if thought of at all, any form of control would entail expense, and for some unknown reason expenditure in such a direction is looked upon as a gamble at long odds, and not an investment of a small amount of capital which will almost certainly bring a better return than the other working capital invested in the business.

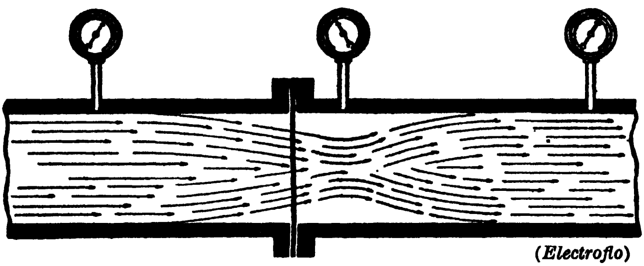
Power-house engineers, although they possess no instruments, will frequently assert that the conditions are at maximum efficiency when there is not an atom of foundation for the statement, and cases are on record when following such statements, tests have been made showing the possibility of very large savings.

In order to operate a boiler plant efficiently, the following measurements are necessary. Fuel consumed, steam produced, and heat wasted; it is also advantageous to measure the water used.

The coal is easily weighed, and the instruments necessary for the other measurements will be meters showing the rate of flow of steam and water, the

quantity of steam and water, the percentage of CO_2 in the flue gases, the draught and temperatures at various points in the system.

The accurate measurement of the rate of flow of liquids or gases through a pipe has, until recent years, proved a difficult matter. We have had meters such as the ordinary house gas meter which registers the total amount passed over a period (this type is known



(*Electroflo*)

FIG. 11

as an integrating meter) but not the rate of flow at any particular moment, otherwise an indicating meter.

There are three methods generally used for measuring a flow, viz. the Venturi tube, the Pitot tube, and the orifice plate, all of which are forms of differential measurement.

One of the best known ranges of meters for such measurements is the "Electroflo"; in these the orifice plate is generally adopted, and a description of their working should prove of interest.

If a thin disc having a hole through its centre is fitted across a pipe through which a flow is taking place, it causes an obstruction with consequent difference in pressure between points before and immediately after the disc; this is shown diagrammatically in Fig. 11.

Providing that the hole is reasonably large in relation to the pipe or the maximum flow, the obstruction and

loss is negligible, and it is found that the pressure is regained almost immediately after the obstruction is passed. It is obvious that if there is no flow there will be no difference in pressure, and it is found that as the rate of flow varies, various differences in pressure are indicated. It, therefore, only remains to devise an instrument which will indicate or, if necessary, record these differences, and this may be accomplished by either mechanical or electrical means; the latter is preferable as the standard of electrical measuring instruments is exceedingly high, and the necessity for elaborate means of reducing or compensating for friction losses inherent in mechanical contrivances is obviated.

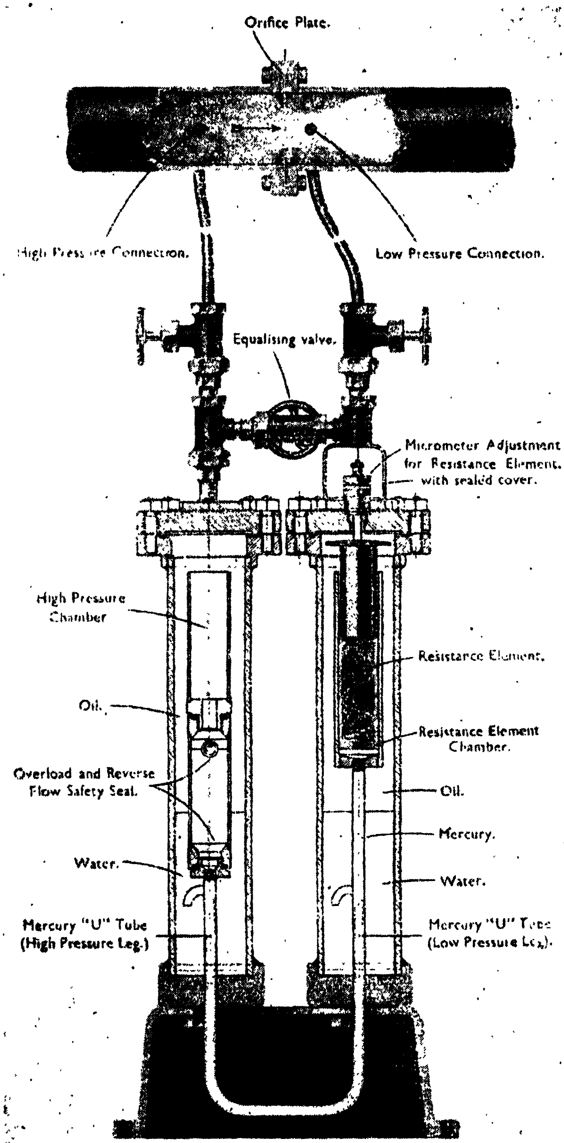
If all that is required is some visual indication that the difference in pressure has changed, it is sufficient to connect the two points, one before and one immediately after the orifice plate, each to one end of a U-tube containing mercury. The mercury will rise in the leg which has the lower pressure, and fall in the leg connected to the higher pressure. If the tube is made from glass, this movement will be visible, but will not be very useful as it is not easy to interpret as an actual measurement.

In the "Electroflo" system this movement is indicated, recorded, or integrated, and shown in figures which interpret the variations of the mercury column as actual rate of flow.

The commercial instrument corresponding to the mercury-filled U-tube is known as the meter body (Fig. 12). Here the U-tube is of steel, and safety devices are included.

We know that the electrical current, through a resistance connected across a constant voltage will be constant unless the resistance is varied. A decrease in the resistance increases the current; conversely, an increase in the resistance will decrease the current.

An electrical resistance is carried above the mercury



(*Electroflo Meters Co., Ltd.*)

FIG. 12. DETAILS OF STEAM METER

in one leg of the U-tube, and so arranged that the mercury makes contact according to its height, with more or less of the resistance. When the mercury is at its lowest level no contact is made, and the current is at zero; as it rises it first makes contact so that the whole of the resistance is in circuit, gradually reducing the resistance as it rises higher.

The current through the circuit can be measured and recorded by an ammeter, and it now only remains correctly to proportion the resistance and calibrate the ammeter to show rate of flow in the pipe instead of amperes, and we have a simple and reliable instrument for giving all the particulars we require.

(Electroflo)

FIG. 13

The current can be used to operate one or all of the following meters—

1. *Indicating Meter.* Visual indication of the rate of flow at the moment; useful to the operator.

2. *Recording Meter.* Tracing a line on a continuous chart recording for future reference all variations of the indicating meter; useful for checking the past operation.

3. *Integrating Meter.* Showing the total amount passed since the meter was last set; useful for comparison of results and costing.

For the integrating meter an instrument is used which is similar to the house-service meter for measuring the electrical power supplied.

Any or all of these meters may be situated at a distant point and connected by ordinary electrical wiring. A panel fitted with 3 meters is shown in Fig. 13.

The CO_2 meter, of necessity, must contain mechanical moving parts, as a portion of the gases must be taken from the flue, measured, the CO_2 extracted, measured

again, and the result indicated on a dial. This entails mechanical and chemical operations, and the intrusion of the chemist has meant, in many cases, the inclusion of glass and fragile parts more suitable for laboratory work. It is possible, however, to obtain CO_2 meters which are made throughout of metal, and in which the moving parts are robust and immersed in oil. Such meters are suitable for use in the rough conditions usually associated with the boiler house.

Fig. 14 shows an "Electroflo" CO_2 meter.

A pump driven by a very small electric motor draws a sample of the gas from the flue and discharges it into a cylinder where it is measured; from this cylinder the measured quantity is forced through a solution of caustic potash contained in a tank which forms the base of the instrument. The potash absorbs all the CO_2 in the sample of gas and the remainder is transferred to another small cylinder, rather like a gasometer, which rises to a height corresponding to the volume of the residual gas after the CO_2 is extracted. A pointer recording this height on a dial suitably calibrated is operated momentarily by this cylinder each time it rises, and held in the position of the last record while the cylinder is taking a fresh charge. The pointer, therefore, moves with a series of impulses at short intervals.

The movement of the pointer can be transmitted electrically to show at any convenient point the percentage of CO_2 at any moment, or to operate a recording instrument showing how the percentage has varied in the past.

The measurement of the draught is accomplished by means of an instrument operated by a float which rises or falls on the surface of a liquid enclosed in a tube, the liquid rising or falling according to the pressure to which it is subjected by connection through a pipe to a chamber or flue.

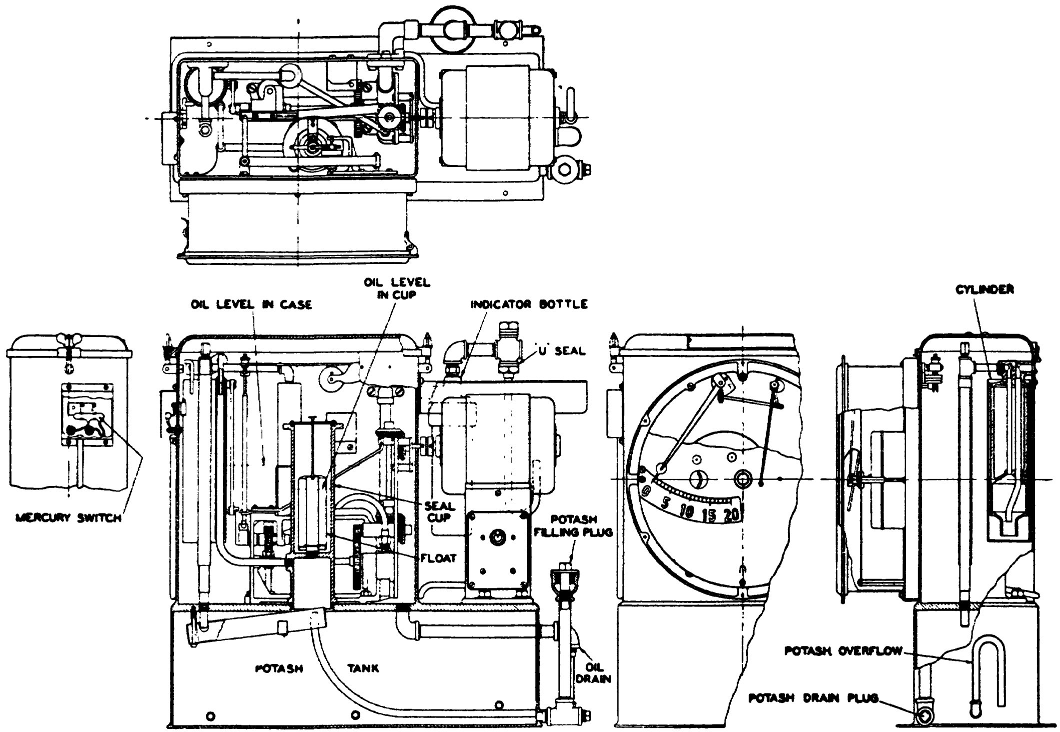


FIG. 14. ELECTROFLO MOTOR-DRIVEN CO_2 INDICATOR AND RECORDER

Temperatures are measured, if low, by thermometer, or, if high, by pyrometer.

The electrical pyrometer of the resistance type depends for its operation on the property, which is possessed by all metals in varying degree, of change of resistance with change of temperature. If, therefore, a resistance of suitable material is subjected to a constant voltage, the current through it will vary according to the temperature in which it is placed, and an ammeter in circuit may be calibrated in degrees of temperature.

The pyrometer of the thermo-couple type depends on the principle that if two dissimilar metals are placed in contact at two points, and one point of contact is heated and the other remains cool, a difference in electrical pressure is set up between the hot and cold contacts, and consequently a current will flow; the difference in pressure and consequently the flow of current will depend upon the difference in temperature. The current is passed through an ammeter calibrated in degrees of temperature, and very high temperatures may be measured by this means. The combination of two metals in this way is called a thermo-couple.

Standards of figures applicable to every plant cannot be laid down, as much will depend on conditions, such as general design, type of boiler, and fuel used. After instruments are installed, experiments will be made to ascertain the conditions governing the evaporation of the maximum amount of water at the minimum cost of fuel and the most efficient load for each boiler.

These conditions can then be repeated, and as time goes on improvements leading to increased efficiency will be made and the meters will make possible the measurement of the results.

A business can only be run efficiently when the demand for the product is known. With a fluctuating demand, in order to estimate the trend and be prepared

to meet it, the more recent the figures on which the estimate is based the greater its accuracy.

A stoker cannot control a boiler on happenings which are recorded for him some time after their occurrence. For instance, if he has a pressure gauge only to indicate the state of affairs and the demand for steam increases, for a time the reserve of the boiler meets the demand of which there is no indication; finally, when the reserve is exhausted the pressure drops, and it is only by special efforts and waste of fuel that normal is regained.

On the other hand should the demand fall, time elapses until the pressure rises, it is then impossible to reduce the fire at once and unnecessary fuel has been consumed.

If steam-flow meters are available, the variation in demand is indicated at once, the recording meter will show the general trend, and steps can be taken without further delay to meet the altered circumstances.

A steam-flow meter on each boiler will enable the load to be correctly distributed between the boilers. Only a sufficient number of boilers should be used, and each should be loaded to its point of maximum efficiency.

The feed water must also be metered, the rate of flow being indicated and the total amount used over a given time measured.

The indicating meter enables the flow to be controlled to correspond with the demand for steam as indicated by the steam-flow meter, and the integrating meter enables comparisons to be made between the weight of water evaporated and the amount of fuel consumed.

The draught indication will be based entirely on experimentally ascertained figures which are found to be best for the particular plant, and is useful only to enable previous conditions to be repeated.

The CO_2 meter, as previously explained, is of the greatest value, and its readings are used in connection with those of the temperature. As much as 30 per cent or more of the heat of the fuel may be lost up the chimney, whereas 15 per cent or less would be a reasonable figure.

The CO_2 proportion should be about 13 per cent; this is lower than the theoretically possible maximum, but for various reasons, generally, a higher percentage is too near the danger mark at which CO and unburnt gases pass over owing to a deficiency of air.

Increased CO_2 up to this point means a higher furnace temperature with increased transference of heat to the water and a lower temperature of gases leaving the furnace. If the temperature of these gases under constant conditions of CO_2 tends to increase, the necessity for boiler scaling and cleaning is indicated, as the scale and soot or slag is heat-insulating the water, and absorption of the heat is being prevented.

Another reason which may give rise to hot flue gases is defective baffles, and these should be examined.

If the percentage of CO_2 is low, one or more of the following causes is indicated.

1. Incorrect damper settings or dampers out of order.
2. Air leaks through cracks in furnace brickwork, boiler settings, or round graters.
3. Bad stoking causing uneven fire, i.e. thin places or holes.

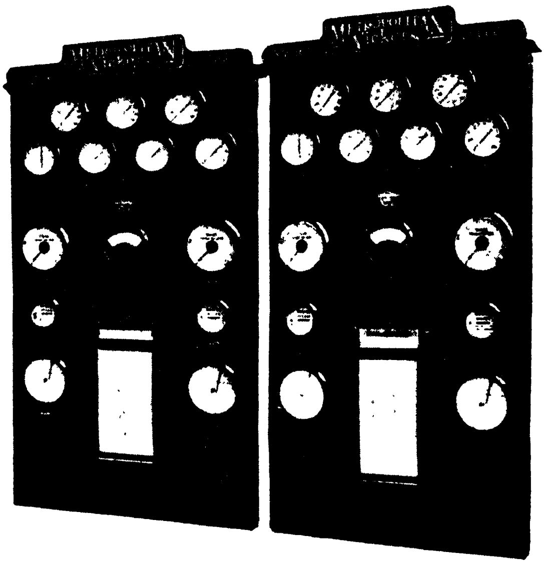
If the CO_2 is unusually high, insufficient air is the cause.

Flow and temperature meters are also used at other points in the plant, and their application will be noted as called for by further description.

This outline of the principles and methods of the control of steam-generating plant should be sufficient to call attention to any point at which waste most generally takes place, and consequently at which there is the

most scope for increased efficiency, and if it has drawn sufficient attention to promote further investigation in any particular plant, undoubtedly a saving can be effected.

In a very large plant it has been found economical to bring all the instruments to a switchboard at a central



(*Electroflo*)

FIG. 15. ILLUSTRATION OF CONTROL BOARD, SHOWING A NUMBER OF METERS ON A PANEL

point, with a combustion engineer in charge. When this is done the firemen and others work simply to the engineer's instructions and are not expected to exercise any initiative.

SUMMARY OF CHAPTER VI

Meters are essential for the proper working and control of the power plant.

The following measurements are necessary: fuel consumed, steam produced, and heat wasted.

Electrical indication and interpretation of the conditions is the best.

Indicating instruments show the state at the moment.

Recording instruments show the momentary state at any given time in the past.

Integrating instruments sum up the total amount which has passed the meter since it was last set.

CO_2 meters indicate and record the percentage of CO_2 in the flue gases by taking actual samples and analysing them.

The indications of the meters can be transferred electrically to remote points.

Temperature is measured by electrical pyrometers, medium temperatures by the resistance type, and high temperatures by the thermo-couple type.

After instruments are installed experiment to ascertain the conditions giving maximum efficiency, and by the aid of instruments repeat the conditions.

A pressure gauge only indicates change of steam demand after the event.

A steam-flow meter indicates change of demand at the time it happens.

The causes of low CO_2 percentage are—

1. Dampers set wrongly.
2. Boiler settings or brickwork defective.
3. Bad firing.

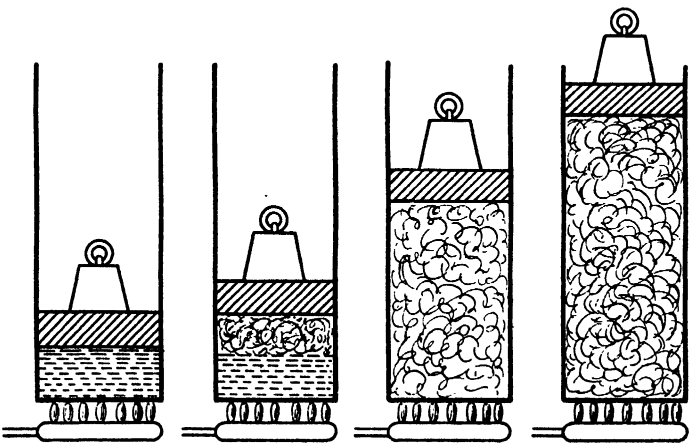
The proper use of instruments is the only way to ensure efficiency.

CHAPTER VII

THE STEAM ENGINE

In Chapter II we noted the effect of heat on water, but before proceeding to the construction and working of the various types of engine it is advisable to consider in more detail the principles of conversion of the energy in steam into mechanical energy.

If we apply heat to water contained in a cylinder, Fig. 16 (*a*), provided with a weighted piston free



(*a*) (*b*) (*c*) (*d*)

FIG. 16. THE EFFECT OF HEAT APPLIED TO WATER

to move in an upward direction, for some time the water will absorb heat and the piston will not move.

As soon as the water boils, steam is produced and the piston rises (*b*); the heat being applied is then doing work by moving the weight against gravity. The weight will continue to rise until all the water is converted into steam (*c*); the steam is now in the condition

known as *dry steam*. If the heat is applied further the dry steam will increase in volume and raise the weight still higher; this condition is then known as *superheated steam*, and it will have to give up this additional heat before returning to the liquid state of water.

What happens when the source of heat is removed? First the superheated steam gives up its heat and we return to the conditions shown in (*c*) at the point where the last drop of water has just been evaporated.

The dry steam then begins to condense into water, and in this condition, i.e. steam in the presence of water, it is known as *wet steam*. As the steam condenses the piston falls until it returns to the conditions shown in (*a*), the whole of the steam having been condensed to water again.

From this experiment we learn that, firstly, in order to convert water into steam it is necessary to supply a large amount of heat before any steam is produced, and, further, that this heat does no useful work as it does not raise the weight. As all the feed water used in a boiler has to be heated in the same way to boiling point, this loss is continually being experienced.

We next notice that after the boiling point is reached, the steam given off can be made to do work; and finally, that superheated steam can fall in temperature without condensing to water.

Without introducing calculations, it is obvious that considerable heat is used in every boiler for two purposes, i.e. raising the temperature of the water and supplying the latent heat necessary to convert the water into steam at atmospheric pressure; as a source of power this steam is of very little use, and it only become useful when the pressure is increased, and even then the maximum efficiency can only be obtained by expansive working, that is, by adopting means to take advantage of the expansion of the steam due to a gradual fall of pressure in the cylinder or turbine.

An important point to note also is that, remembering that although the temperature of saturated steam depends on and is constant with the pressure, very little extra heat is required to raise the pressure of steam, hence the increased efficiency obtainable by working at higher pressure.

This expansive working is perhaps a little difficult to understand without entering fully into the theory and mathematics of the steam engine. Everyone knows that when a gas is compressed, although its weight remains the same, its volume is considerably decreased, and that if the pressure is released the gas expands and continues to expand in volume until it reaches atmospheric pressure, and, further, that if it is released against something less than atmospheric pressure its volume would be increased still further.

Steam at 100 lb. per square inch behaves like a gas compressed to about one-sixth of its volume at atmospheric pressure. If steam at 100 lb. per square inch is admitted to a cylinder behind a piston we know that it pushes the piston forward. If the admission of steam is continued for so long as the piston is moving forward, at the end of the stroke we have a cylinder full of steam at 100 lb. per square inch pressure, and therefore capable of doing a considerable amount of work before it has been expanded to the pressure of the atmosphere into which it must be discharged in order to allow for the entry of more steam.

Two courses are open for the further use of this steam. It can be discharged into one or more other cylinders consecutively, each one allowing it to expand more until its pressure is reasonably reduced, such a method being known as compound if of two cylinders only, or triple or quadruple expansion if three or four cylinders are used; or the entrance of steam may be cut off from the cylinder after the piston has moved forward for only a short distance, the pressure on the

piston for the remainder of the stroke being supplied by the steam as it expands to a lower pressure. Even in the compound or multi-cylinder expansion type the cut-off point must still be early in the stroke, and the multi-cylinder expansion engines have really been introduced to take full advantage of high pressures which are too great for economy in a single cylinder.

It must be remembered that as steam expands its temperature falls, and should it fall to a point below the boiling point at the pressure at which the steam happens to be, it will condense to water and is of no further use ; in fact, its presence as water in a cylinder is a disadvantage and may become a danger.

The cylinder walls also tend to cool and, therefore, condense the steam. Ordinary dry steam only contains sufficient heat to retain it in the form of steam at its original pressure ; therefore, any reduction in temperature, without corresponding reduction in pressure, means condensation. In a pipe or cylinder in communication with the boiler, condensation will not cause a fall in pressure, as the deficiency due to the condensation is immediately made up, but it is obvious that the greatest efforts must be made to avoid condensation, hence the introduction of superheating.

Steam cannot be superheated in the presence of water, but steam issuing from the boiler may be taken through the hot furnace again by passing it through pipes as shown in Fig. 7, page 60, and given additional heat units which can be given up again without condensation taking place, and by this means the loss of latent heat energy, due to condensation in pipes and cylinders, may be avoided, and more advantage taken of the power of expansion.

The steam engine of the present day may be either of the reciprocating type, having one or more cylinders fitted with moving pistons giving rotary motion by operating on a crank, or of the turbine type, in

which the pressure of the steam operates directly on moving vanes attached to a shaft which is capable of rotation.

The cylinder of the reciprocating engine is a short tube usually of cast iron, closed at one end by a fixed cover, and at the other by a similar cover through a gland in the centre of which passes a piston rod which, inside the cylinder, is fixed to a piston which is movable and free to slide for the whole length of the cylinder. A steam-tight joint is made between the piston and the walls of the cylinder by fitting round the piston one or more gun-metal or cast iron rings. Mechanical means are adopted to pass the steam first to the one and then to the other end of the cylinder behind the piston, thus giving the piston a reciprocating movement which is translated into rotary motion by joining the piston rod by means of a suitable connecting rod to a crank on which a flywheel is mounted.

Assuming that the piston is just past the limit of its travel at one end of the cylinder, when steam is admitted to the small space left between the piston and the cylinder cover, pressure is exerted by the steam on the piston, the actual measure of the pressure in pounds being the area of the piston in square inches multiplied by the steam pressure in pounds per square inch.

As soon as this pressure becomes sufficient to overcome the resistance offered by the inertia of the moving parts, the load, if any, and the back pressure of the atmosphere on the other side of the piston, the latter moves forward, turning, by means of the piston rod and connecting rod, the flywheel. If the pressure of steam is continued, the flywheel will move through half a revolution and then stop, owing to the piston having arrived at the other end of the cylinder; if means are provided to release the pressure on the piston and transfer it to the other side, rotation will continue for another half revolution, and so on.

Sometimes engines are arranged so that steam is admitted to one end of the cylinder only, the return stroke being made by means of the kinetic energy stored in the flywheel. Such engines are described as *single-acting*; if steam is admitted to both ends of the cylinder alternately the engine is said to be *double-acting*.

Engines may be run either *condensing* or *non-condensing*, that is, the exhaust steam, after it has been used in the cylinder, may either be passed through a condenser and reconverted to water, or it may be discharged into the atmosphere.

The travel of the piston is so arranged that when at its limit in either direction (this point is called the dead centre) a small space is left between it and the cylinder cover. This space should be kept as small as possible as it has to be filled with steam, which is wasted, at each revolution.

The outside of the cylinder is usually covered with some heat-insulating material to prevent loss of heat and consequent condensation. At each end of the cylinder, communicating with the space not swept by the piston, is fitted a cock to allow condensed water to be drawn off, as an accumulation of water might result in the cylinder cover being forced off.

On one side of the cylinder will be found a box or another small cylinder containing the mechanism controlling the admission of steam.

The simplest form of such control is the slide valve. On one side of the cylinder is cast a rectangular box which is provided with a steam-tight cover; the bottom of the box is machined perfectly flat, and sliding on it is a thick plate, called the slide, also machined flat on its sliding surface. In the flat surface of the bottom of the box will be found three rectangular holes called "ports"; the two outer openings connect by passages cast in the cylinder with the two spaces,

left by the travel of the piston, at each end of the cylinder; the centre opening connects to the exhaust pipe. (See Fig. 17.)

The flat underside of the slide is provided with a cast recess which allows, according to its position,

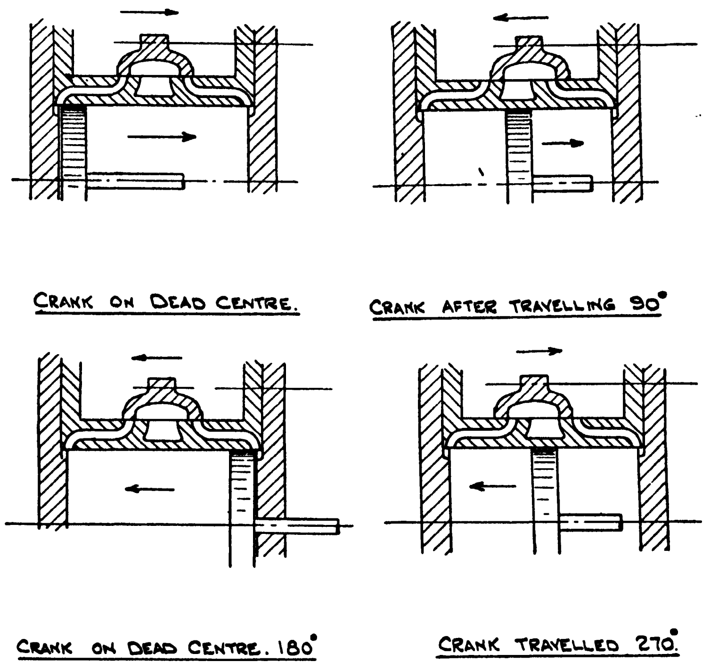


FIG. 17

either the one or other of the outer ports to communicate with the centre or exhaust port.

In the wall of the box is an opening to which is fitted the steam pipe communicating with the boiler; thus the box is always full of steam at boiler pressure.

An eccentric on the crankshaft is connected to the slide, and the rotation of the crankshaft gives a reciprocating movement to the slide which corresponds to the movement of the piston in the cylinder.

The action is as follows: Assuming that the piston is at the back end of the cylinder ready to begin its forward stroke, i.e. at dead centre, the slide valve is then at the centre of its stroke, the two steam ports being just covered by its flat face.

The least forward movement of the crankshaft, carrying with it the piston and slide, will slightly uncover the port communicating with the cylinder and thus admit steam behind the piston; at the same time the other port is put in communication with the exhaust.

As the piston travels forward the valve at first moves with it, but the position of the eccentric on the crankshaft is so arranged that the slide arrives at the end of its stroke when the piston has travelled half the length of the cylinder, and by the time the piston has reached the other end of the cylinder the slide has returned to its central position, but it is travelling in the opposite direction. The valve then admits steam through the other port to the other side of the cylinder, forcing the piston back and allowing the steam used for the first stroke to escape through the exhaust pipe.

This is the simplest setting of the slide valve, but when it is understood it will be easy to see that the length and position of the face of the slide can be modified to enable the steam to be cut off at any point in the stroke so that full advantage can be taken of the expansive power of the steam.

Further, the valve set as described, allows steam to enter just as the piston travels forward on its stroke. If the eccentric is given a slight forward movement relative to the crank, the steam will enter a little earlier, making a cushion for the heavy mass of the piston which has to stop and change its direction of motion and also be ready to push it forward at once on its fresh journey. On some engines, locomotives for example, arrangements are made to enable the point

of cut-off to be varied while the engine is running, as while the greatest economy is obtained by an early cut-off, more power to meet an emergency is available if the cut-off is later.

In order to obtain the maximum efficiency, the ports should be opened and shut to their full extent instantaneously. The slide valve, by reason of its mechanical design, cannot give this very quick motion.

The slide valve is sometimes made in the form of a piston or two pistons working on the same piston rod; as by this form of construction much larger ports can be used; this gives the same effect as a quicker opening, and this effect may be further increased by combining a form of spring trip gear which accelerates the motion at the particular moment required.

The Corliss valve gear consists of four semi-rotary valves, one for steam admission and one for exhaust, in pairs at each end of the cylinder; as they are operated by a combination of eccentric and cam gear very quick motion is obtained.

As previously stated, after the steam leaves the cylinder it may either pass direct into the atmosphere or to a condenser.

The interior of a condenser is connected to a pump and kept at a lower pressure than the atmosphere; this applies a suction to the exhaust steam and consequently is equivalent to working at a higher steam pressure than without a condenser. This is one advantage, but it also has the defect that unless the steam is fully expanded the opening of the exhaust valve to a pressure very much lower than that of the steam remaining in the cylinder with the consequent reduction in temperature, owing to the reduction in pressure, will cause condensation in the cylinder itself which is not required. Therefore it is not advisable to use a condenser with an engine working on high-pressure steam unless it is of the compound or multiple

expansion type, as it would not be possible to allow sufficient expansion of the steam, when passing through one cylinder only, to reduce the pressure to a suitable degree.

Another advantage of the condenser is that the used steam is reconverted to water at a high temperature which can be returned to the boiler and will not require so much heat to reach boiling point, and further, that the hardness in the water causing scale is deposited the first time the water passes through the boiler, and more scale will only be produced on the introduction of fresh water; consequently, the necessity for frequent cleaning is eliminated.

There are two types of condenser: jet and surface.

In the jet condenser the exhaust steam is cooled by passing it into a chamber in which it meets a spray of cold water which condenses the steam with which it mixes.

The resulting water, consisting of fresh water and condensed steam, passes to the hot well from which it is pumped to the boiler.

One of the disadvantages of this type is the introduction to the boiler of fresh water which will carry with it salts in solution causing the deposit of scale. The jet condenser is now almost entirely superseded by the surface type.

There are many types and shapes, but the principle of keeping the exhaust steam separate from the cooling water is maintained in all surface condensers. In some the exhaust steam passes through a number of pipes in a chamber through which cold water is circulated, but the more usual practice is to pass the steam into a chamber containing a large number of tubes through which cold water is passed. By means of baffle plates the steam is made to pass first between the tubes containing the hottest water, and finally to meet the pipes at the point where the water enters and is consequently cooler.

The casing of the condenser may be cylindrical or of any other convenient shape, and is usually built up from steel plate. Pumps are necessary to circulate the cooling water and provide the vacuum.

It should be remembered that the main object of the condenser is to neutralize the back pressure of the atmosphere on the piston at the end from which the

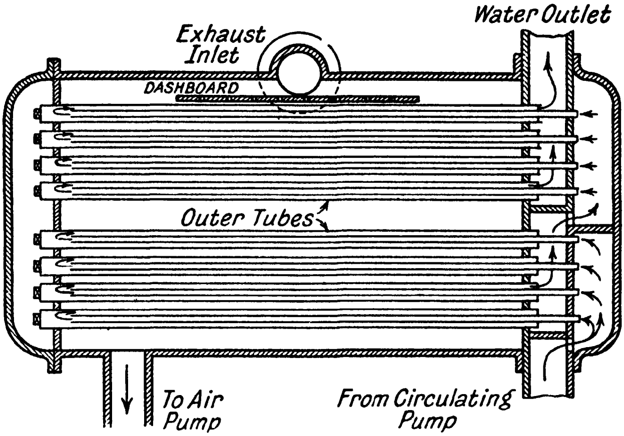


FIG. 18. A TYPICAL SURFACE CONDENSER

steam is being exhausted, and consequently the maintenance of a good degree of vacuum is important. The loss of 1 in. of vacuum may mean 7 per cent increase in steam consumption.

The instruments already described may be used to measure the vacuum, the rate of flow, and amount of the condensate, and similar measurements may be taken of the cooling water. These figures, in conjunction with the differences in temperature, will enable the quantity of lost heat to be calculated and possibly efficiency improved.

While it is beyond the scope of this book to explain how such calculations can be made, it will be obvious that by chemical analysis the heat obtainable from a

fuel can be calculated, the various losses, many unavoidable, traced by suitable instruments, and steps taken to ensure that the plant works at its maximum efficiency.

It is interesting to note that the reciprocating steam engine was not the earliest type of engine to convert,

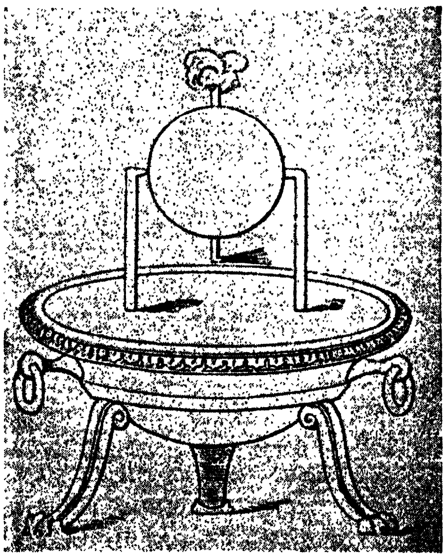


FIG. 19. HERO'S STEAM ENGINE

by the aid of steam, heat energy into mechanical power. Long before James Watt, according to tradition, sat before the fire and watched the pressure of steam lift the lid of a kettle of boiling water, Hero of Alexander (130 B.C.) invented the first steam turbine, shown in Fig. 19. A closed container over a fire was filled with water and the resulting steam carried by a pipe through a bearing to the interior of a globe which was free to rotate; the globe was provided with two oppositely directed nozzles through which the steam issued, and the reaction of the pressure of the steam issuing

to the air provided sufficient power to rotate the globe. This type of machine, in which the steam expands in the moving part, is known as a *reaction* turbine, and is not efficient; it is used, however, in conjunction with the impulse method, to be described later, in the Parsons turbine, which is strictly a reaction-impulse turbine.

In the *impulse* turbine the heat energy of the steam is converted into kinetic energy by allowing it to expand before meeting a series of moving blades. The velocity of the steam thus becomes very high, and it can impart a large amount of energy to the blades and keep them in continuous rotation.

There are various types of steam turbine, the best known being the De Laval, Curtis, Zoelly, Rateau, and Parsons.

In the De Laval type, which is pure impulse, the steam emerging from a series of jets, arranged at a suitable angle, impinges on concave vanes arranged round the periphery of a wheel, the whole being enclosed in a suitable casing. The wheel is mounted on the shaft and is rotated directly by the kinetic energy of the steam.

In both the Curtis and the Rateau types the steam, after passing one series of blades, is again passed through nozzles and made to impinge on one or more further series of blades.

Fig. 20 shows a section of a Parsons turbine.

The rotor carries a series of blades of increasing diameter as shown at *B*, *C*, *D*. The casing is fitted with stationary blades which project inwards between the revolving blades; suitable bearings are provided at each end of the rotor.

The steam, which is usually super-heated, enters the small diameter at *A*; it passes alternately through the stationary and moving blades, the pressure falling at each step at which the diameter is increased.

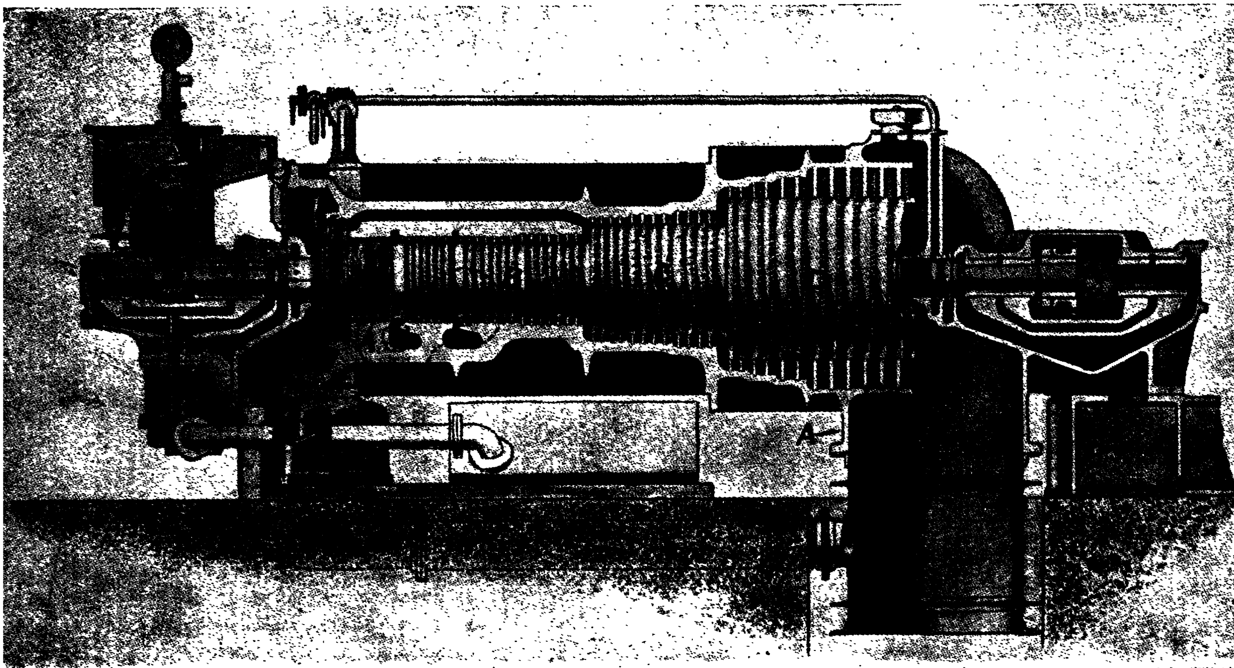


FIG. 20. PARSONS STEAM TURBINE

The pressure of the steam on the blades sets up a considerable end thrust, and to balance this thrust pistons *F*, *E*, and *C* are mounted on the main rotor shaft; the diameter of these pistons corresponds to the diameter at each stage *B*, *C* and *D*, and steam from each of these stages is admitted behind the corresponding piston thus counteracting the end thrust.

On account of the necessity of using the steam at a very high velocity and the mechanical limitation of the size of the turbine rotor, the shaft of a turbine must rotate at a very high speed, occasionally 30,000 r.p.m.; this is much too great for direct gearing for driving machines or tools, consequently a turbine for industrial power is always directly connected to an electrical generator and the power is transmitted electrically.

Turbines are used with condensers, and sometimes the exhaust steam is taken through a low-pressure turbine before being condensed.

Summary of Chapter VII

The effect of heat on water in a closed space—

1. Water absorbs heat: no steam is generated.
2. Steam is generated and produces increase in volume, but no rise in temperature.
3. Water is all converted to steam and temperature rises.
4. Steam is superheated.

If the source of heat is removed the sequence is reversed.

In a boiler heat is lost in raising the temperature of the feed water.

Superheated steam can give up heat without causing condensation.

The latent heat used for converting water to steam at atmospheric pressure is lost.

Expansive working is necessary to obtain full advantage of high steam pressure.

At high pressures in order to utilize to the full the expansion of the steam, several cylinders, through which the steam passes in succession, are necessary.

Two such cylinders are termed compound.

Three such cylinders are termed triple expansion.

Four such cylinders are termed quadruple expansion.

Superheating prevents pipe line and cylinder condensation, and thus promotes efficiency.

Steam engines are of the reciprocating or turbine type.

The reciprocating engine must be fitted with self-operated valves to control the admission and exhaust of the steam.

Turbine engines are rotary only, and have no such valves.

A condenser prevents boiler scale and, allowing the engine to discharge to a pressure below atmospheric, increases efficient working.

There are two types of condenser: jet and surface.

The surface condenser is the type in common use, as the exhaust steam can be kept separate from the cooling water.

It is important that a good vacuum should be maintained; a loss of 1 in. may mean 7 per cent increased steam consumption.

There are three types of turbine: reaction, impulse, and a combination of reaction and impulse.

Turbines must run at a high speed, therefore they are most suitable for driving electric generators.

CHAPTER VIII

INTERNAL COMBUSTION ENGINES

LATENT energy can be taken from any fuel and converted into mechanical energy without the use of steam boilers, which are only used in the steam plant as a vehicle for the transfer of energy.

Coal, for instance, may be treated and the carbon converted into an explosive gas; this, mixed with the hydrocarbon gases given off in the distillation of coal, can be used in the internal combustion engine. Usually when used thus, the latter is termed a gas engine.

In the ordinary gas works coal is heated in retorts and the volatile hydrocarbons are driven off and conveyed through pipes for domestic and other consumption. The residue is practically pure carbon in the form of coke. For a small power plant it is sometimes sufficient to draw a supply of coal gas from the mains to be used in an internal combustion engine for driving machinery; but it is almost always cheaper to produce a gas specially for the engine. Gas plants have now been developed to a considerable size; they occupy less space than a steam plant of the same output, and when steam as such is not required in the manufacturing process it is often more economical to use the gas plant.

The gas producer plant for this purpose usually consists of two main parts, the producer and the scrubber. The fuel is preferably anthracite, as it is cleaner than the bituminous coals. The passage of steam mixed with a small amount of air through a red-hot bed of carbon results in the production of a mixture of gases of which carbon monoxide and hydrogen are the most important; both of these gases are inflammable, and explosive when mixed with air. (Fig. 21.)

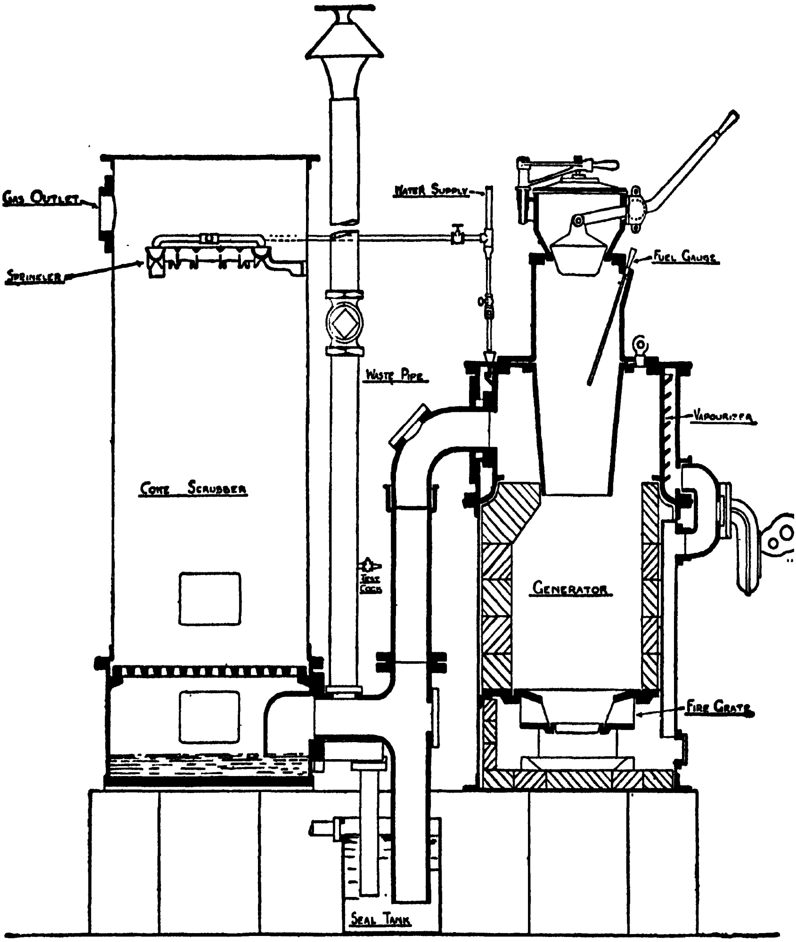


FIG. 21. NATIONAL SUCTION GAS PLANT (ANTHRACITE FUEL)

The producer consists of a steel cylinder placed vertically, and at the top is an annular chamber containing water to supply steam.

Through the centre of this chamber passes a hopper to feed fuel to the fire of red-hot coal which is in the lower part of the cylinder. Suitable doors are provided for the admission of air and removal of ash. The fire-box is lined with fire-bricks and made quite airtight.

The scrubber for cleaning the gas is also a vertical steel cylinder filled with coke, which is kept wet by a continual spray of water from the top. The air and steam are drawn through the fire by the suction of the piston in the engine, the resultant gas passing through the scrubber to which the producer is connected by a pipe entering the scrubber near its base. The gas is taken from the top of the scrubber through a gas box which is usually filled with sawdust and serves as a small reservoir for the gas.

An alternative method is to force the mixture of steam and air through the fire by a blower; the resultant gas is collected in a gasometer in which it is stored and drawn off as required.

If the method of relying on the suction of the engine for the passage of the air and steam is adopted and the load falls for a time, the reduced demand will cause the fire to die down, and should a heavy load be thrown on suddenly, the engine may not be able to obtain sufficient gas. This type, known as a suction gas plant, is therefore most suitable for a steady load.

The pressure gas plant, on the other hand, will be provided with ample storage capacity to meet load variations, and having the gas available it can be used for heating and other purposes just as ordinary coal gas is used.

The theoretical heat units in a certain amount of fuel can be ascertained, and the ratio between the

mechanical equivalent for these and the work done by the engine represents the efficiency of the plant.

The losses are principally in the heat carried away by the hot exhaust gases and the water used for cooling the cylinder. A good gas plant has an efficiency of from 25 to 35 per cent.

Reverting to the construction of the cylinder of a steam engine, it will be obvious that if, instead of the application of steam pressure, an explosion takes place in the closed cylinder behind the piston, it will be driven forward and, through a crank, can impart rotary motion to a shaft. This is the principle of the working of the internal combustion engine.

For constructional reasons these engines are not made double acting, and the production of power takes place on one side of the piston only, consequently the energy for the return stroke must be supplied from the rotating flywheel. Further, as in order to obtain the best results the explosive mixture must be highly compressed before explosion, and the majority of makers compress the gas in the cylinder itself, using a return stroke of the piston for the purpose, it is possible to obtain a power stroke once only in every two revolutions of the flywheel. This series of operations taking place in the cylinder is known as the Otto Cycle, and is illustrated diagrammatically in Fig. 22.

Internal combustion engines are made in which the gas previously compressed is admitted to the cylinder at the end of the exhaust stroke and, consequently, a power stroke is obtained once in every revolution, but the great majority adopt the Otto Cycle.

The entry of the gas mixed with the proper proportion of air, either admitted with the gas or mixed in the cylinder, to form an explosive mixture, is through a valve usually of the mushroom type opened

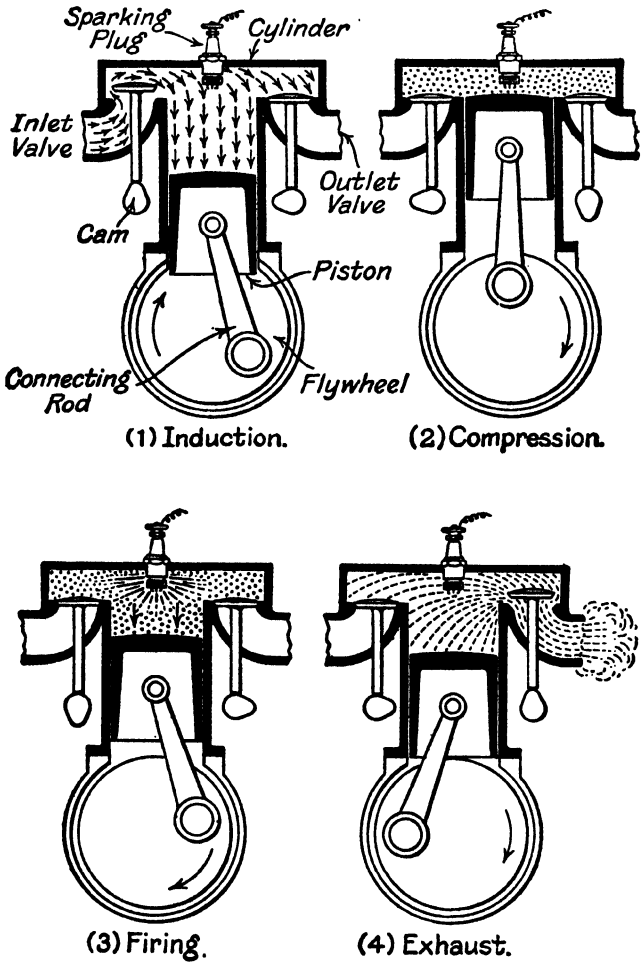


FIG. 22
ILLUSTRATING THE OTTO CYCLE

by a cam and closed by a spring. An exhaust valve is operated by a similar manner.

The explosion of the mixture is now almost universally by means of an electric spark provided by the magneto, although some old engines are still in operation in which the charge is fired by being given access to the interior of a platinum or porcelain tube which is kept continuously at a red heat by means of a gas jet.

As crude oil can replace coal as fuel under a boiler, so it can be used in an internal combustion engine; in this case there is no necessity for a gas producer, as at high temperatures the oil forms a gas. The best known crude oil engine is the Diesel type.

In these the air only is admitted to the engine during the suction stroke and highly compressed on the compression stroke to over 500 lb. to the square inch. At the beginning of the firing stroke a jet of fuel oil is sprayed into the cylinder through a valve; this fine spray mixes with the air which has become, through high compression, sufficiently hot to ignite the mixture; on the exhaust stroke the burnt gases are expelled.

With the crude oil engine there is thus no necessity for any special means of ignition, but a small compressor is required to feed the oil to the cylinder.

Petrol engines work on the same principle as the gas engine, but are little used for commercial power production.

Internal combustion turbine engines remain to be developed; up to the present there is no commercial type.

The losses in an internal combustion engine are chiefly in the form of heat from the explosion given up to the water, which is circulated round the cylinder in order to keep it sufficiently cool to allow proper lubrication and prevent the gas exploding during compression before the piston has reached the correct point. The other losses are from the high temperature

of the exhaust gases and through friction of the moving parts.

It is, of course, assumed that the mixture of the fuel and air is correct for the maximum effect on the piston of the explosion of the charge, and that the moment of ignition is timed correctly.

Raising the pressure of the compression will increase the efficiency, as the mean pressure on the piston during the working stroke is higher, a weaker mixture may be used and less burnt gas is left in the cylinder at the end of the exhaust stroke. Therefore, raising the compression enables greater power to be obtained from the engine without using more fuel.

If the compression is raised to too high a point, there is danger of pre-ignition from the high temperature attained.

Pre-ignition means that the charge is exploded too soon, so that its effect is felt on the piston before it has finished the compression stroke; the effect of this is a tendency to turn the flywheel in a reverse direction, consequently tremendous strain is thrown on the moving parts.

In the Diesel engine very high compression can be used as there is no explosive mixture until the fuel is introduced at the right moment.

High compression engines must be very sturdily built to stand the pressure, and difficulties in lubrication are also found on account of the great heat developed.

While there is considerable room for improvement in the efficiency of the internal combustion engine, its operation and the control of a suction gas plant are quite simple, and providing instructions given by the makers are faithfully carried out, there is not that scope for possible increased efficiency of operation that is found in the average steam plant.

When working blast furnaces a gas is produced

which has a calorific value of about 100 B.Th.U. per cubic foot. This gas is quite useful for running gas engines which may drive dynamos and generate electrical power which is used as an auxiliary to that already generated for the works.

Before leaving the subject of suction gas plants and internal combustion engines, it is well to note that while in a small plant little use can economically be made of the impurities in the gas, in a large plant it is possible to extract from the scrubber valuable by-products, the sale of which assists in reducing the cost of production.

An aid to efficiency of a producer plant is to heat the air and water used for the production of steam. Heat otherwise wasted in the exhaust gases of the engine may be utilized for this purpose.

A final note is a warning that one of the constituents of suction-produced gas is carbon monoxide; it is almost odourless, invisible, and extremely poisonous even when present in small quantities in air. This is the gas which, mixed with CO_2, is the cause of the fatal results which usually attend the running of petrol engines in closed garages. A slight leak in the pipes carrying the gas from the producer to the engine or at other points may permit a sufficient quantity of this gas to escape. The least result of a small dose is a headache; a large dose may prove fatal.

Water is seldom used as a source of power in a factory. In America, Sweden, and Switzerland, advantage is taken of the waterfalls for the generation of power in bulk, often transmitted over long distances and distributed for factory and domestic use.

Large water wheels, commonly found driving flour mills in country districts, are of very ancient origin. To be efficient they must be made of the same diameter as the fall which limits their use to falls of about 40 ft. and under.

On falls less than 20 ft. high the turbine is more efficient, therefore the modern practice is to use the water turbine.

From the small study of mechanics which we have made, we know that the work done by the water is the product of its weight and the height through which it falls. For a definite amount of work, therefore, we can use a very high fall and a small amount of water, a low fall and a large amount or any intermediate stage, remembering the higher the fall the less the water required for the same power.

In considering the hydraulic generation of power from a fall, it is necessary to take observations over the whole of a year or even for longer periods. A river which is a raging torrent in the winter may, in a dry summer, become a trickling stream which is of no use for power purposes.

To a certain extent dry periods may be bridged by artificial storage, but it is only possible to know what storage would be required if adequate records are available, consequently the more complete the data showing seasonal variations of flow of the stream the better.

If it is only possible to take records over a few months the records of the rainfall for a district are usually available, and by making comparisons between the known flow and rainfall over one period it is possible to estimate roughly the flow for other periods for which the rainfall only is known.

To ascertain the energy available from a fall of water, it is first necessary to measure the volume flowing per minute over the fall. The usual method is to construct a weir across the stream and provide in the weir a notch through which all the water will flow. The difference in height between the bottom of the notch and the level of the water a little distance behind the notch, combined with the width of the

notch, will give a constant which, used in conjunction with tables given in engineering handbooks, will enable the flow to be ascertained in cubic feet per minute. The height of the fall is usually easily measured.

The weight of the volume of water falling per minute, multiplied by the height of the fall in feet, will give the foot-lb. per minute.

The division of this amount of work by 33,000 will be the total theoretical horse-power available. This figure will then be multiplied by the efficiency of the turbine.

The formula will be stated as follows—

$$\text{H.P.} = \frac{\begin{pmatrix}\text{Weight of water in lb.}\\ \text{falling per minute}\end{pmatrix} \times \begin{pmatrix}\text{height}\\ \text{of fall}\end{pmatrix}}{33000} \times \begin{pmatrix}\text{efficiency of}\\ \text{turbine}\end{pmatrix}$$

Water turbines are rotated by the reaction of the water flowing from the curved surfaces of the blades. Guide blades are arranged to ensure the water meeting the blades at the right angle.

The speed of a turbine will depend on its diameter and the velocity of the falling water; if the fall is low and the turbine is used for driving an electric generator it may be necessary to adopt some form of gearing between the turbine and generator in order to keep the size of the latter within reasonable dimensions.

Whatever form of prime mover is adopted to convert potential energy into work, its power is presented in the form of a rotating shaft which may be at any speed up to about 30,000 r.p.m., according to the type of prime mover. This power has to be conveyed from the shaft to the point at which the work, such as driving a machine, has to be done.

Three methods are in general use: in a small plant by mechanical transmission in which the shaft of the prime mover is fitted with a pulley which is coupled

by means of a belt, ropes, chain, or other gearing to a shaft which is thus rotated, being carried in bearings, and extends, possibly with the aid of other gearing, to the point at which the power is required.

Alternatively, for a larger plant, the shaft of the prime mover may either be coupled direct or by gearing to an electrical generator. The power is then transmitted by conversion into electrical energy through cables to the desired point or points where it is reconverted into mechanical power for use as desired.

Another form of power is pneumatic, in which, by means of a pump, air is compressed and transmitted through pipes to the desired point. The energy is converted to mechanical power by air engines, turbines, or other mechanical appliances. This method of transmission is usually used only for small portable tools in which case the convenience outweighs its disadvantage of low efficiency.

Summary of Chapter VIII

Latent energy in fuel can be converted into mechanical energy without the use of steam boilers.

Fuel is heated to incandescence, and the passage of a small quantity of steam produces inflammable and, when mixed with air, explosive gases.

These gases are cleaned, mixed with air and, being exploded behind the piston in an internal combustion engine, give mechanical energy.

The losses are in the heat carried away by the exhaust gases, and the heat lost to the water necessary for cooling the cylinder.

The internal combustion engine can use spirit, paraffin, or crude oil as a fuel, in which case a gas producer plant is not required.

If crude oil is used a spark is not necessary to cause the explosion, ignition being obtained from the great heat due to high compression.

Raising the compression pressure increases efficiency.

In large suction gas plants, valuable by-products may be extracted from the gas.

Carbon monoxide is extremely poisonous.

Water power is little used for directly driving of machinery in factories.

Generally the greatest efficiency from water power is obtained by the use of water turbines.

CHAPTER IX

ELECTRICAL GENERATORS

When an electrical conductor is moved through a magnetic field in such a direction that it cuts the lines of force (see Chapter III) a difference of potential is set up in the conductor, and if the two ends outside the field are connected together, as the lines of force are cut, that is for as long as the conductor is moving in the field, a current will flow round the circuit.

This is the principle of all generators used for the conversion of mechanical to electrical energy.

All that is required for the above effect is relative movement between the conductor and the magnetic field. Either can be stationary as is the more convenient; for instance, if a conductor is wound in the form of a hollow spiral and a bar magnet is moved along its axis, for as long as the magnet is moving a current will flow if the ends of the spiral are connected to form a closed circuit.

We have seen that soft iron retains its magnetism for only so long as it is under the influence of a magnetizing force, which may be either a permanent magnet or a coil carrying a current; supposing a coil with a closed circuit is wound round a bar of soft iron and the iron is magnetized by being brought under the influence of a magnet or other means, at the moment of the iron becoming magnetized a current will flow, owing to the movement of the magnetic field being built up. As the magnetizing force is removed a momentary current is produced again owing to the movement of the magnetic field dying away; this time the current will be in the opposite direction to that when the magnetism was being built up.

It is also found that the potential difference or

voltage induced in a conductor by cutting lines of force is proportional to the speed at which the lines are cut, i.e. to the revolutions per minute of the generator.

If the magnetic field is very weak, that is, there are few lines per unit area, the conductor would have to move much more quickly than in a dense field for the same voltage to be produced.

Remember that the current flows only while the conductor is moving. It is quite easy to understand

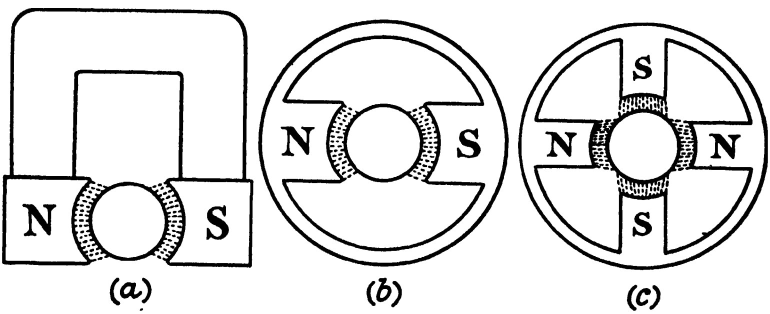


FIG. 23. TYPES OF MAGNETIC FIELD FOR MOTORS AND DYNAMOS

this. Energy in one form must be provided to produce energy in another form. If a conductor in a field is stationary, no energy, either mechanical or chemical, is exerted, and no change is taking place, therefore no current flows; directly either is moved, force is exerted to produce the movement and the potential difference is set up.

To convert mechanical to electrical energy, all that is necessary then is to provide a magnetic field and so arrange a conductor that it can be made, by mechanical means, to cut the field and provide suitable means to collect and use the current produced.

Fig. 23 shows, diagrammatically, various forms of magnetic circuits used for this purpose, the field being indicated by dotted lines.

A generator with a magnetic circuit as in (*a*) is called a two-pole machine. The two poles may also be arranged as in (*b*), which is equivalent to (*a*), but the iron connecting the two poles is split to form two magnetic circuits between them; (*c*) represents a four-pole machine, and similar machines are made having a much greater number of poles.

The air space across which the lines pass is called the "air gap," and it is through this space that the conductors are moved.

As the resistance of air to the passage of magnetic lines is very high, a central iron core is provided between the poles to reduce this resistance and obtain the strongest possible magnetic field with the minimum expenditure of magnetizing force.

This iron core becomes, by induction, a magnet, and, as it is usually made to rotate, the magnetism is always changing relative to the iron.

Some small amount of energy is absorbed by this change, and it forms one of the losses incidental to electrical generators; it is necessary, however, to provide some support for the moving conductors, and the convenience provided by winding them on this part and rotating the whole together outweighs the small loss.

The rotating part is called the *armature* or *rotor*, the stationary part the *field magnet* or *stator*.

In the early days permanent magnets were used for field magnets; now the practice of using electromagnets, i.e. iron frames magnetized by winding them with a coil or coils carrying an electric current, is universal.

When a conductor cuts a magnetic field a current is produced in one definite direction; if the conductor cuts it in the opposite direction the direction of current is also reversed.

Fig. 24 shows a single loop of wire cutting a magnetic

field. Taking one side of this loop which is rising past the north pole, as it rises a current will be induced from front to back; as it falls on the opposite side it is equivalent to reversing its direction of rotation, as the pole outside it is a south pole (opposite polarity) and the current will tend to pass from back to front; therefore, in the left-hand of the loop the current is tending to pass in the same general direction as that in

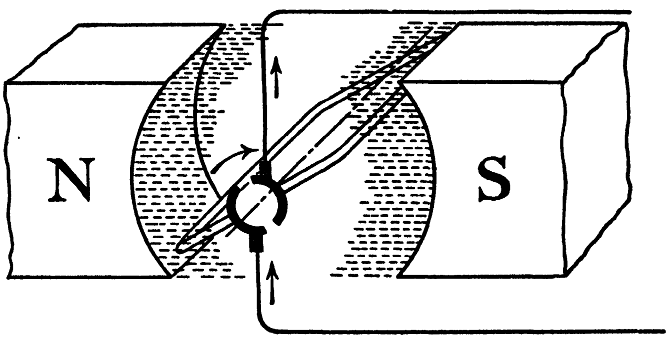


FIG. 24. WIRE LOOP CUTTING MAGNETIC FIELD

the right-hand side, and continue in the same direction throughout the circuit until the coil is vertical. Directly the part of the conductor which was rising starts to fall and pass the south pole, the direction of the current in it is reversed, and if it is necessary that the current in the external circuit should be always in the same direction, means must be provided to connect the rising side, on the left hand, always to one end of the external circuit, and the falling side on the right hand to the other end, as the end connected to the rising side gives always the same electrical polarity—under the conditions in the diagram – *ve* and the falling side + *ve*.

This is accomplished by a device known as a *commutator*, shown diagrammatically; each end of the loop

conductor is connected to half a split ring which rotates with the conductor; the two halves being insulated, the one from the other.

The current for the external circuit is drawn off from the ring by *brushes* usually of carbon (an electrical conductor). These brushes are arranged diametrically opposite so that each is in contact with one-half of the ring only at the same time.

An examination of the diagram will show at once that by this means one end of the external circuit is always in connection with the rising side of the loop and the other end connected to the falling side. Therefore, although in the loop the direction of current is changed every revolution, the current outside is unidirectional, and this is known as *direct* or continuous *current*: the former being the term most commonly used and frequently contracted to D.C.

If the ends of the loop are each connected to two separate complete rings placed side by side on the central spindle, known as *slip-rings*, and each ring has on it a brush connected to the two ends of the external circuit, the current through the external circuit reverses in direction at every half revolution of the loop and is described as *alternating current.*

As is generally known, electrical generators are known as either dynamos or alternators, the former delivering D.C. and the latter A.C.

As has been implied, a number of loops may be wound on the armature and their ends connected so that the voltage given by the generator is the result of the voltages due to all the loops; in other words, they may be connected in series or in parallel or a combination of both, just as the cells of a battery may be connected as described in Chapter III. In this case the commutator will have a large number of segments connected to the various loops.

We have seen that the voltage of a generator is

dependent on the speed at which the lines of force are cut, otherwise the r.p.m. of the machine, consequently an electrical generator must be driven at a constant speed to give a constant voltage, and the prime mover to which it is coupled must be very well governed.

Any undue increase in speed causing increased voltage would result in too much current being passed through lamps and apparatus in the circuit with the consequent danger of their burning out. It would also result in the generator being called upon to deliver more current, and if that were more than the windings would stand, the armature might burn out.

Supposing that you are turning a dynamo by hand, and that it is connected to a circuit in which are a number of electric lamps capable of being switched on singly.

If all the lamps are switched off you find it an easy matter to rotate the armature. This is because, although you are creating a potential difference or a voltage across the terminals of the machine, it is delivering no current, and consequently the energy required is only sufficient to overcome the friction and other small losses.

Now have the lamps switched on, one at a time. As their number increases you find it harder and harder to turn; finally, it becomes so hard that you have to turn more slowly. As the speed falls the lights become dim, the voltage having dropped, and therefore is not high enough to drive sufficient current through the filaments to keep them white hot.

It all seems very mysterious, as the only apparent resistance to motion in the machine is the friction of the brushes; there is nothing else rubbing. It should be noted that the power required to drive a generator increases with the load, and if the load is reduced the demand on the prime mover is reduced too.

Electrical generators are very efficient, the larger

machines being rather better in this respect than the small ones. The efficiency falls off as the load is reduced, and it is generally arranged so that maximum efficiency is obtained at full load, any overload causing a slight reduction.

A 1,000 kW generator might reasonably have an efficiency of 95 per cent at full load, dropping to 90 per cent at $\frac{1}{4}$ load, and 93 per cent at $1\frac{1}{2}$ load. When this is compared with the efficiency of the steam plant it is obvious that the generator is not the first part to look to when seeking improvement.

In studying the generator we have seen that in addition to supplying a steady current in one direction, that it is possible to generate a current rapidly alternating in direction. For certain purposes this alternating current is preferable to direct current, but, as may be imagined, it differs somewhat from direct current in its effects. A steady direct current flowing through a wire produces a definite magnetic field round the wire, and as long as the current is steady the field remains unaltered. An alternating current through a wire produces a magnetic field which is constantly going through the process of being built up, broken down, and then built up and broken down in the reverse direction; consequently, whereas a closed circuit, placed in the magnet field of a conductor carrying steady direct current, will have a current induced in it only at the moment of making and breaking the direct current circuit, if a closed circuit is placed in the field surrounding a wire carrying alternating current, owing to the variation of the magnetic field due to the alternating nature of the electrical flow, current will be induced which is as frequent as the changes in the wire carrying the primary alternating current, and is consequently alternating current too.

This effect is intensified if two wires are wound for several turns side by side on an iron bar. The presence

of the iron increases the magnetic field, and by this means alternating current can be transferred from one circuit to another without metallic contact between the circuits. An instrument of this kind is called a *transformer*, the wire carrying the original current is called the *primary* winding, and the wire carrying the induced current the *secondary* winding.

Suppose the secondary winding has twice as many turns round the core as the primary, we then find that,

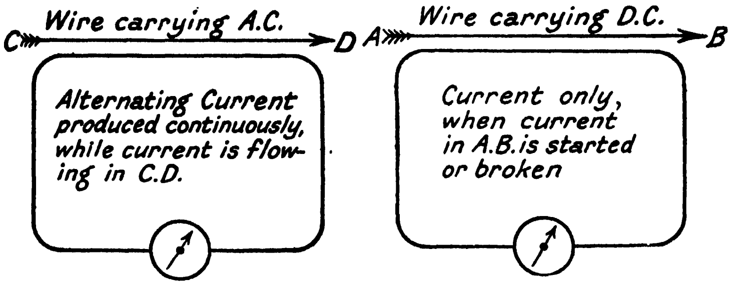


FIG. 25. EFFECT OF CURRENT ON AN ADJACENT CIRCUIT

under these conditions, as the secondary winding cuts the magnetic lines produced by the primary twice as many times as the primary, the voltage across the ends of the secondary winding is twice that of the primary: the relation between the primary and secondary voltages always varies as their relative numbers of turns.

If it is desired to transfer power electrically to a distance, we know that the size of the conductor must be sufficient to carry the current flowing.

The power transmitted will be measured in watts, which varies as the product of amps multiplied by volts. Therefore, if the volts are increased for a certain power, amps will be decreased thus for D.C.—

100 amps at 500 volts = 50,000 watts.
10 amps at 5,000 volts = 50,000 watts.

If we wish to transmit 50 kW at 500 volts we shall need a cable of about $\frac{1}{10}$ sq. in. in sectional area. To transmit the same power at 5,000 volts would require a cable of $\frac{1}{100}$ sq. in. area only. There would thus be a considerable saving in first cost of the transmission line.

If we are using direct current it is not commercially practicable to change the voltage to 5,000, but if alternating current, a transformer can be used at the starting point to change the voltage from 500 to 5,000 (the proportion of turns on its primary and secondary windings being as 1 : 10), and, if necessary, by the use of a similar transformer connected the other way round the voltage can be stepped down again at the receiving end to 500 volts, or any other convenient value.

The transformer has no moving parts, is simple in construction, and consequently low in first cost and cheap to maintain; it is also extremely efficient. To change the voltage of direct current a motor coupled to a dynamo is necessary; it has none of the advantages of a transformer and is seldom used.

For short distance transmission there is little difference between the cost of alternating current and direct current. Thus, for a private supply at a works, unless it is wished to use a public supply as a standby, direct current would generally be adopted, as for some purposes more suitable motors can be found and there is the advantage that with direct current an accumulator can be installed for running lights at night or even a small load.

In a modern power plant of any size the generator is always directly coupled to the engine; that is, there is no gearing or belting used, the armature or rotor of the generator forming an extension of the engine shaft.

For this reason the generator will run at the same speed as the prime mover.

Steam engines may be reciprocating (i.e. with cylinders and pistons) or of the turbine type.

In a large reciprocating engine the weight of the pistons is considerable and, further, they move along the cylinder at a considerable velocity. At the end of each stroke the piston must be brought to rest and put in motion again in the opposite direction. To do this very rapidly would put a considerable strain on the working parts. There is a limit to the speed at which steam can be admitted to and exhausted from a cylinder as the size of the ports cannot be greater than that allowed by the dimensions of the cylinder.

For these reasons a reciprocating engine cannot be run at a very high speed.

Large engines may run at about 100 to 150 r.p.m., medium sizes about 200 r.p.m., and smaller engines 300 to 350 r.p.m. Steam turbines, having no reciprocating parts and no slide or equivalent valve mechanism to control the flow of steam, which is constant and steady, can be run at very high speeds, 30,000 r.p.m. being quite possible for small machines.

We have seen that the voltage of a generator, depending on the rate at which the lines of force are cut, will vary almost exactly with the speed; thus, if we have a machine running at 500 r.p.m., giving 250 volts and *keeping the magnetic field constant*, we run that machine at 1,000 r.p.m., it will give 500 volts.

The maximum current output of a generator depends mainly on the size of the conductor with which the armature is wound, and is accordingly independent of the voltage. Supposing, therefore, that the windings of the machine would carry safely a maximum of 1,000 amps, the output at 500 r.p.m. would be—

1,000 amps at 250 volts = 250,000 watts = 250 kW.

at 1,000 r.p.m.—

1,000 amps at 500 volts = 500,000 watts = 500 kW.

It appears, therefore, that by doubling the speed of a

machine we can double its output, and within certain small limits this is true.

As there is little difficulty in designing generators for very high speeds, and as we have seen the higher the speed the smaller the machine for the same output, if a high speed machine can be used the first cost is considerably reduced. Therefore, the generator to be used, coupled to a high-speed turbine, would be considerably smaller than a machine of the same output coupled to a steam engine, and a combined turbo-generator can be built for a much larger output than a single reciprocating engine coupled to a generator.

The wear on a turbine is chiefly on the blades which are slowly worn away by the friction of the steam, and at intervals a turbine will require reblading. The bearings will also need attention at times. A reciprocating engine will wear the piston rings, cylinders, valve faces, and bearings; the upkeep will consist of reboring cylinders, refacing valves, and attending to a number of small and main bearings.

The nature of the load is the deciding factor in settling the individual units of power-house equipment. The maximum normal load may be carried by all the machines running at their most efficient point with some spare set or sets to meet breakdowns or allow for plant out of commission for overhaul; emergency overloads may be met by overloading the machines. If there should be a steady normal load, one large unit would probably be the best way to meet that demand with smaller units to carry periods of light load. The important principle is to provide machines so that each *large* variation in load is met by introducing or cutting out a unit or units; to meet the demand by running the minimum number of units, and to arrange that each unit is so loaded that it is working at maximum efficiency.

The current for magnetizing the fields of the generators must be provided. In direct current machines this is taken from the main supply, the generators themselves supplying the exciting current. If the generators are for alternating current, which, owing to its frequent reversal would not magnetize the fields suitably, the necessary direct current is provided from small dynamos called *exciters*; these may be driven from an alternating current motor or mounted on an extension of the generator shaft.

Summary of Chapter IX

An electrical conductor moving through a magnetic field will generate current; this is the principle on which electric generators are designed and constructed.

The voltage across the ends of such a conductor depends on the strength of the magnetic field and the relative velocity of the two.

Generators may have any number of pairs of magnetic poles, each pair consisting of one N. and one S. pole.

When a loop rotates so that it passes N. and S. poles alternately, an alternating current is generated.

Alternating current is taken directly from the windings of the machine.

To obtain direct current the alternating current is rectified by a commutator as it leaves the windings.

A commutator is a mechanical device for providing that all current leaves the generator in the same direction.

To give a constant voltage a generator must run at a constant speed.

The generator takes power from the prime mover only as required by the electrical output demanded.

The efficiency of electrical generators is very high, 90 per cent being common in large machines.

The voltage of D.C. can only be altered by the use of moving machinery.

The voltage of A.C. can be altered by the use of a transformer, an appliance consisting of wire wound on an iron core and having no moving parts.

The efficiency of a transformer is very high, often 95 per cent.

A high-speed generator is very much smaller than a low-speed generator having the same output.

High-speed generators are used with steam turbines.

D.C. generators will supply their own current for magnetizing the fields.

A.C. generators must be supplied with D.C., generated by a small dynamo, for magnetizing purposes.

In laying out a power house, units are arranged so that different combinations will meet the varying load. Also a stand-by must be provided to allow for overhaul without shutting down the entire plant.

CHAPTER X

CONTROL AND DISTRIBUTION OF ELECTRICAL ENERGY

WE have already dealt with certain units used for measuring current (Chapter III); these are directly applicable to direct current, but when used with alternating current some modification is necessary.

Direct current is a continuous flow from the point at high voltage $+ ve$ to the point at lower voltage $- ve$.

Alternating current in the same terms is a flow of current from a point momentarily at a maximum $+ ve$ to a point momentarily at a minimum, $- ve$. The voltage at the points is rapidly changing from a maximum to a minimum, till the point which was $+ ve$ becomes $- ve$ and the $- ve$ becomes $+ ve$. This change, which depends on the r.p.m. and number of poles of the generator, is usually arranged to take place 50 times per second, measuring from the moment at which a main is at maximum $+ ve$ until it is at maximum $+ ve$ again. The current flowing in a circuit, being due to the pressure, naturally rises and falls in the same way. The frequency of this change is called the *periodicity* or *frequency* of an alternating current supply. Other frequencies than 50 are used; 60 is common in America, and 25 is found in parts of England and on the continent of Europe. A low frequency has the disadvantage that, if used for lighting, the change of the current from maximum through zero to minimum is so slow that it will cause a momentary diminution in the light of the lamp which is slightly apparent as a flicker.

The frequency of the circuit is usually found marked on the electricity supply meter; for 50 period supply it would be expressed as "50 cycle" or simply "50 $\sim$."

The rise and fall of the current or voltage can be graphically indicated by a curve as in Fig. 26.

The part of the curve below the horizontal line indicates a pressure or flow in an opposite direction from the part above. An illustration of direct current in the same manner would be a straight horizontal line at a height corresponding to the steady voltage.

Supposing an ammeter or voltmeter could be made sufficiently sensitive to follow the actual variations

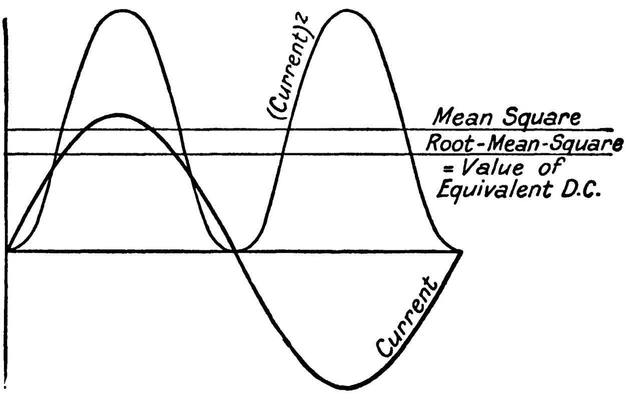


FIG. 26

of the current, the readings, if the eye could also follow them, would be of little actual value; so for measurement purposes instruments generally for alternating current work read what is called "virtual amps" or "virtual volts." These instruments do not indicate an average, but the square root of the mean of the squares of the instantaneous values, with the result that practically they indicate the measurement of the equivalent D.C

For measuring the watts taken by lamps or heaters the amperes multiplied by the volts will be correct, but in the case of motors and apparatus incorporating electromagnets in their construction, some modification is necessary as will be seen later.

Alternating current is supplied either *single-phase* or *polyphase*, the latter is either *two-phase* or *three-phase*. Two-phase is very rare, but alternating current power is almost always three-phase.

The details of the method of producing three-phase current is beyond our scope, but roughly it must be accepted that if, instead of tapping an armature at two diametrically opposite points and connecting to slip-rings from which single-phase is taken, we tap at three equidistant points at 120° apart and connect to

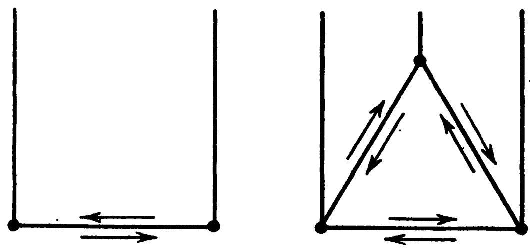


FIG. 27. ILLUSTRATING SINGLE- AND THREE-PHASE CURRENT

three slip-rings, the current from these rings will have the property that if it is connected to three points on a closed spiral winding a rotating magnetic field will be produced, which is equivalent to a magnet mechanically rotated. This principle is very useful in alternating current motors.

Thus, while for a single-phase supply two wires only are required for mains, in a three-phase supply we have three wires, and while if the two wires of a single-phase main are connected the current oscillates through the connection backwards and forwards, if the three wires of the alternate current mains are connected the current oscillating between the pairs is so timed that the general effect is also rotary. Fig. 27 may help to give some comprehension of this rather difficult point.

Lamps and small single-phase motors can be used

and connected across any pair of mains in a three-phase circuit, but large motors are three-phase and connected across the three mains.

We have seen that if two separate coils of wire are wound on an iron bar and one is supplied with alternating current, it will induce a current in the other coil. If one coil only is wound on an iron bar and it is supplied with alternating current it will tend to induce a current in itself, as each turn will act on the turn next to it just as if it were a coil in another circuit. The current which it tends to induce will be equal in magnitude and opposite in direction to the original current; consequently, it nearly neutralizes the original current and very little current will pass. In a transformer, if current is taken from the secondary, this effect in a primary is neutralized by the secondary current flowing, but if no current is taken from a transformer it is found that very little current is taken by the primary owing to the above cause.

This action of such a winding, which is similar in effect to the resistance to direct current, is known as *reactance* and is measured as its equivalent in *ohms*. To find the alternating current passed through a circuit at a certain voltage, if that circuit includes a motor or other apparatus having a magnetic winding, it is necessary to take into account the reactance thus.

$$\text{Current} = \frac{\text{volts}}{\sqrt{(\text{resistance})^2 + (\text{reactance})^2}}$$

Such a circuit is known as an *inductive* circuit, and it is said to contain *inductance*.

An inductive circuit, such as one including a motor or motors, has another peculiar effect on alternating current: it makes the current appear as if it possessed inertia. Imagine a backward and forward flow of water through a pipe, the flow being produced by a

piston. Owing to the inertia of the water, the flow would not take place directly the pressure was exerted by the piston, but would lag slightly behind.

In the same way in an inductive circuit, the current lags slightly behind the volts. This effect applies both to single- and polyphase alternating current.

The work done by the current is the product of the amps and volts at the same moment, therefore, on an inductive circuit, as the current is lagging behind the volts, the actual useful current is less than the amount measured by an ammeter. This lost current is called wattless current, and the ratio between the watts as obtained by a wattmeter and the product of the readings of a voltmeter and ammeter is called the *power factor*; a fair average figure for this is 0·8. When alternating current power is obtained from a supply company they sometimes meter the current supplied in amps, therefore this wattless current has to be paid for and steps should be taken to make the power factor as near unity as possible. Condensers or an over-excited synchronous motor in circuit will do much to improve the power factor as they both tend to make the amperes lead instead of lag as in the inductive circuit.

In order to ascertain the watts in a three-phase circuit, if the load is balanced, such as a motor load, it is necessary to multiply the amps in one phase by the volts, and by a factor of 1·732. This figure represents $\sqrt{3}$ and is used in all such three-phase calculations.

A direct current supply is sometimes carried by three wires and is then known as a three-wire supply. In a *three-phase* supply the voltage between any two of the three wires is equal, but in a *three-wire* direct current supply the voltage of either of two of the wires, one $+$ *ve* and the other $-$ *ve*, to the other wire called the neutral will be the same, but between $+$ *ve* and $-$ *ve* will be found a voltage double that of from either $+$ *ve* or $-$ *ve* to the neutral.

The advantage of the three-wire direct current system is that the central wire need only carry a small current.

Heavy loads are connected across the *outers* which have the higher voltage, and consequent current economy. Lamps, however, must be used on a lower voltage, which is given between one of the outers and the neutral; if the lamps are connected some on either side of the neutral they can be arranged to balance each other so that the neutral carries only the small out-of-balance current which will be dealt with at the power station by a balancer.

If lighting is required and only a high voltage is available, and the supply is alternating current, a trans-

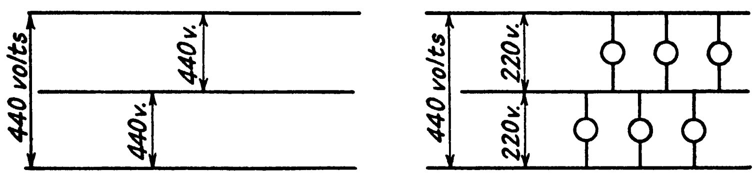


FIG. 28

former can be used to change the voltage from, say, 440 to 220. If the supply is direct current, and the neutral is not available, two lamps, each of half the supply voltage, can be used connected in series across the high voltage, but if this is done care must be taken to see that they both take the same current, or, in other words, are of the same resistance, otherwise the lamp having the higher resistance will burn out on account of the voltage not being split evenly.

The resistances of the lamps can be calculated by the formula given in Chapter III. Fig. 29 shows, diagrammatically, two similar lamps and two dissimilar lamps connected across 400-volt mains.

The current from the generators is led to a switchboard at which it is metered, controlled, and distributed as required.

A switch is the means, usually a pivoted bar of copper, whereby by making or breaking metallic contact between two points in an electrical circuit the flow of current may be controlled at the will of the operator.

Switches are fitted with various additions such as automatic quick-break carbon contacts to take the

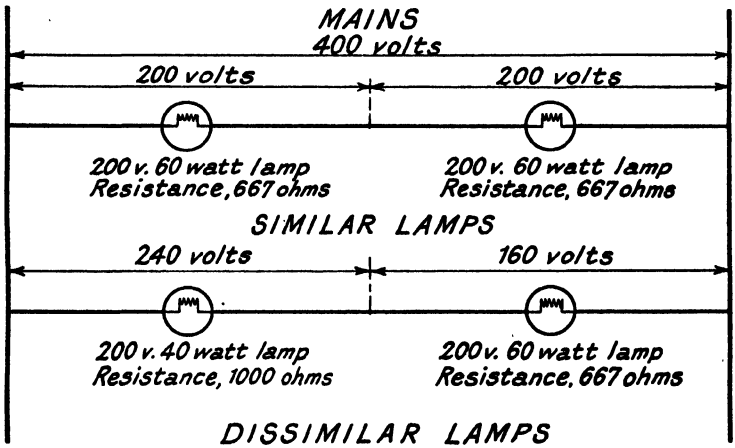


FIG. 29

spark on breaking, etc. Some for high voltages work entirely submerged in oil.

When fitted with automatic features which cause the switch to open circuit with certain alterations in current passing, such as an excess current, no current, or perhaps no voltage, it is called a *circuit-breaker*.

On power station switchboards, if the voltage is low, switches or circuit breakers are mounted direct and without enclosure on slate or marble panels; if the voltage is high they are mounted behind or away from the board, usually in oil tanks, but are controlled from the front of the board on which the measuring instruments are also mounted.

Fuses consist of strips of metal of such a section that they are melted by an excess current and thus open the circuit. They are usually only used for low voltages and small currents.

A switchboard for a power station will usually have a separate panel for each generator on which is mounted an ammeter to show the current the generator is giving, a voltmeter to show the pressure and the necessary switches. There will also be a resistance and switch to control the output of the generator.

The current is taken from the generators to two or more bus-bars which extend the whole length of the board. The switches connect or disconnect the generators and the bus-bars. Next to the generator panels is usually a panel containing instruments which show and measure the total output of the generators, and following this panel a series of panels controlling through switches the distribution of the current to the various departments. These panels will contain meters to enable the departmental consumption to be observed and measured. Cables are run from the distribution panels to the various departments or points which it is convenient to make the centres for sub-distribution.

For convenience in paralleling generators, in place of the voltmeter on each generator panel, it is often the practice to mount two voltmeters on a bracket at the end of, or above, the board; one of these is permanently connected to the bus-bars and the other by means of switches or plugs can be connected to any one of the generators.

When it is found that the demand is exceeding the capacity of the generators working, a fresh generator is run up to speed until the voltage is the same, or very slightly higher than the voltage across the bus-bars if the supply is direct current; the switch is then closed, and by adjusting the strength of the magnetic field of

the generator it is made to take its proper share of the load.

If the supply is alternating current, before closing the switch the generator must be brought into synchronism with the generators already running, that is, the voltage curve of the generator must coincide at its peak or any other point with that of the generators already connected, and the speed must be the same so that the periodicity is also equal.

There is one other feature sometimes found on direct current switchboards, that is, means such as switches and instruments for charging a battery; it would be very unusual for a battery to be installed to carry the full load, but if there is no stand-by from a supply company, it is very convenient to be able to provide light in the event of the generating plant being shut down.

With regard to a stand-by from outside if this is available, the voltage and other particulars of the factory system will be the same as that of the outside supply, and switches will be fitted to make the necessary change over.

If, as is quite frequent, the outside supply is alternating current, and brought in at a very high voltage, before use it is necessary to reduce the voltage by means of a transformer. In this case any convenient voltage can be adopted for the factory supply, but the periodicity must agree with that outside.

Where the mains from the switchboard enter the department or other distribution point a distribution board should be fitted. This will have a main switch and fuses, and if not switches, at least fuses will be provided for the motors to which leads will run individually or in groups according to the location and size of the motors.

It is usual to run a separate circuit for lighting, as otherwise the variations in the demand made by

the motors may cause flickering or dimming of the lights.

There are various methods of running cables. It is generally required that in addition to the insulation and protective covering on the core, additional protection shall be given. The old-fashioned wood casing and capping is practically out of date, and in all modern installations the cable is run in steel tube with screwed connections joining the tubing and fittings into one continuous electrical circuit which is connected to earth.

The electrical continuity of the steel tubing and the earth connection is most important, otherwise should a cable become damaged and the charged metallic core be in contact with the tube, if the earth connection is not good a person touching the tubing is in danger of receiving a severe electric shock.

For the same reason the metallic cases of motor starters, fuses, and switches, and the frames of motors and other apparatus are all connected to the earthed casing, or if more convenient, to some other metal such as the steel frame of the building or water-pipe system, which is already in good contact with earth. Gas pipes must not be used for earth connections. The requirements of the Home Office are very strict in this respect, and care must always be taken that installations are in conformity with these and also those of the insurance company.

In wiring for alternating current circuits it is important to note that all the wires, both flow and return, for a particular circuit are enclosed in the same tube. If the circuit is single-phase this will contain one pair, if three-phase, three wires. If one wire only were placed in the tube there would be losses from currents induced in the conduit, but if both or all the wires are in the same tube, the direction of the current in the wires being opposite, this inductive effect is neutralized.

Electric motors are controlled by suitable starting gear. Small motors up to $\frac{1}{4}$ h.p. do not require a starter; they can be switched on with a single switch in the same way as an electric lamp. All larger motors will have some form of starting panel which will, at least, be fitted with a double-pole fuse, switch, and motor starter. Preferably the switch will be double-pole, and this apparatus will all be enclosed in earthed iron cases.

If in a dusty atmosphere, or if inflammable gases or corrosive fumes are present, the cases will be made dust-proof or gas-tight.

Some alternating current motors larger than $\frac{1}{4}$ h.p. may be switched straight on to the mains, but when this is done the electricity supply regulations will require some form of automatic circuit-breaking device, therefore the switch virtually becomes a motor starter.

Electrical measuring instruments may be classed primarily as Indicating, Recording, and Integrating as explained on p. 75 in connection with boiler house instruments.

Ammeters used for measuring the rate of flow of the current are of the indicating or recording type; if of the integrating type the meter is called an ampere-hour meter.

Voltmeters for measuring the electrical pressure and watt-meters for electrical energy are of the indicating or recording type only. The wattmeter of the integrating type is called a watt-hour meter.

The watt-hour meter is the type usually used for measuring the total supply as output from a generator, total out-put from a power station, or for the supply to a department or house, and may be calibrated in B.O.T. units.

The ampere-hour meter is frequently found aaapted for measuring alternating current supply and as the voltage is constant it can be calibrated to read in Kilovolt-ampere-hour units, and it is on this basis that the charge for the supply is usually made, this meter measuring the total supply irrespective of power factor as explained in Chapter XII.

Balancing the Load. It is important to remember that electrical generators, motors, engines, boilers, all run at their maximum efficiency when fully loaded.

A particular application of this is found in the case

of electricity supply. In a generating station the plant will be found to be sub-divided into units frequently of different sizes. As will be appreciated, the load on an electricity supply undertaking varies throughout the 24 hours, and it is usual only to run such a portion of the plant as can be kept at approximately full load.

The establishment of the grid system has enabled further economy to be effected as, if the station is connected to the grid, any surplus needed to keep the plant running at full load at any particular time can often be fed into the grid, and should there be an additional demand not sufficient to warrant starting up another generator, a supply can be drawn from the grid.

In a small factory generating its own electricity supply, if the demand is not sufficient to divide the generating plant into units, it is still advantageous to keep the load as steady as possible and violent fluctuations can be avoided by arranging any exceptionally heavy unit used intermittently to be put into operation at such times as the system is lightly loaded.

In larger factories it will no doubt be found that the generating plant is already arranged in units, and if a recording instrument showing the total load is in circuit it will usually indicate a small steady load throughout the night, rising rapidly to a peak between 9 and 10 a.m., falling off gradually until midday when the drop is very rapid, rising again to a lower peak than the a.m. peak between 3 and 5 p.m. in the afternoon, then gradually falling off to the closing down time. The aim should be in the first place to keep the load as steady as possible during the whole of the working hours.

If the supply is drawn from the mains the same loading conditions will apply, and under the present war conditions it is found that the load on the generating stations generally throughout the country corre-

sponds to that indicated above. The supply of electricity to a factory is usually charged at a fixed price per unit plus an extra for maximum demand; it is therefore very much in the interest of the consumer to keep his maximum demand as low as possible, a high peak for a few hours during any month may mean a very disproportionate increase in the cost of the supply.

At the present time, owing to the shortage of fuel, this point of view becomes national, and it has been found that the high peak in the morning means unnecessary fuel consumption. It is, therefore, both in the consumer's interest and the national interest that every possible means should be taken to keep the load chart as level as possible.

Electricity is frequently used for heating offices, and this possibly accounts to a great extent for the heavy morning peak, if this heating were switched on before the normal time of starting up in the factory; it could be reduced when starting and increased, if necessary, during the latter part of the morning and lunch time.

Electric furnaces are often used intermittently and unnecessarily, there may be many on at the same time and at other times very few; this load, with little inconvenience, could often be spread evenly throughout the day.

There are also some machines or operations which require a heavy current. It might even be advisable when using these to run a special shift at times when the normal factory load is off.

Attention should also be given to motors driving a number of machines. It is often found that, as a general practice, these are very seldom fully loaded. If this is the case the substitution of a smaller motor will again increase the efficiency, as it is better to run a motor normally fully loaded with occasional overload, than to run it normally at perhaps half load and only occasionally at full load.

SUMMARY OF CHAPTER X

Direct current is a continuous flow in one direction.

Alternating current is a flow first in one direction and then in a reverse direction; the complete change taking place many times per second.

This change is called frequency or periodicity; the usual frequency is 50. In America 60 is common; 25-cycle supplies are also used.

Alternating current supplies may be either single-phase or polyphase.

Polyphase is usually three-phase, sometimes two-phase.

D.C. and single-phase A.C. usually are supplied through two wires. (Three sometimes for D.C.)

Three-phase A.C. is usually supplied by three wires. (Sometimes four.)

Single-phase motors and lamps can be connected across any two wires of a three-phase supply.

A choke on A.C. gives the same effect as a resistance on D.C.

On A.C. an inductive circuit causes the amperes to lag in time behind the volts; consequently, useless current is carried by the mains and sometimes paid for by the consumer.

This lag may be corrected by the use of condensers or synchronous motors in the circuit.

In a D.C. three-wire supply the middle or neutral allows small currents at half the maximum mains voltage, to be taken for lighting purposes.

Current from generators is controlled and metered at the main switchboard.

A circuit breaker is a switch fitted with one or more automatic devices to break the circuit, by opening the switch under certain predetermined conditions.

Cables run from the switchboard to distribution boards, whence the circuits are taken to the separate motors.

Motors above ¼ h.p. must be provided with some form of starting switch to reduce the heavy current which would otherwise be taken from the mains at starting.

Electric cables are usually run in steel conduit, which itself must form a continuous electrical conductor and be connected to earth.

Motor frames, iron switch boxes, and other metal used in conjunction with electrical appliances, must be connected to earth.

CHAPTER XI

ELECTRIC MOTORS

THE electric motor is the machine for converting electrical energy into mechanical energy, and for direct current circuits it is simply a dynamo used in the reverse way.

We know that an electric current is induced in a conductor which cuts through a magnetic field, and the converse is true, that if a conductor carrying current is placed in a magnetic field and is free to move, it will do so in such a direction that it cuts the lines of force and tends to move out of the field.

This is the principle on which the electric motor works, the conductors wound on the armature cutting the magnetic field in the air gap and carrying the core and shaft with them.

Electric motors are made with casings either of the protected, dust-proof, or totally enclosed type. For special purposes other types such as drip-proof are used.

The protected type of casing allows free ventilation, often assisted by a fan or blower.

The dust-proof type may have ventilation provided through fine wire gauze.

The totally enclosed type may have ventilation supplied through pipes conveying air from some outside source, in which case it is described as pipe ventilated, or it may be so enclosed that there is no communication with the air inside the machine.

Ventilation is necessary as the losses representing the inefficiency of the machine all appear as heat which must be dissipated. Consequently, as an air circulation is impossible in the totally enclosed machine,

this heat must be carried away from the casing by convection and radiation. For this reason, for the same output the totally enclosed machine will be found to be rather larger than the protected type.

There are three distinct types of direct current motors: the shunt motor, the series motor, and the compound motor. The words shunt, series, and compound refer to the different methods of exciting the magnetic field which varies the characteristic of the motor.

The shunt motor is used where a constant speed is required from no load to full load, the variation under these circumstances usually being less than 5 per cent. The starting torque is not very great and it would not be used when extra power is necessary for starting.

The series motor is useful for cranes and traction purposes as the speed falls with increasing load and the starting torque is very high. If an electric crane is used for lifting a heavy load it moves slowly; it will lift a light load quickly. This action is quite automatic, as it is driven by a series motor which gives the effect of a variable speed gear.

The compound motor has a combination of the characteristics of the shunt and series. The proportion of this combination can be varied by the designer. For instance, the motor may be what is termed heavily compounded, when it will behave more like a series motor, but the speed will not rise so quickly on light load; or it may be lightly compounded with only a gently falling speed characteristic but a better starting torque than the shunt motor. It is therefore better able to deal with occasional heavy overloads. The compound motor is usually designed for the special purpose for which it is required.

An electric motor will run in either direction, and to change the direction of rotation all that is necessary on direct current machines is to interchange the two

leads which are connected to the armature through the brushes.

The speed of a motor may be reduced by inserting a resistance in the armature circuit, the effect of the resistance being to reduce the voltage to the armature and therefore the speed.

The speed of shunt motors may be increased by inserting a resistance in the field circuit and thus decreasing the strength of the magnetism.

A motor and dynamo being of exactly similar construction, the rotation of the armature of a motor by its action as a dynamo tends to produce a current which in direction is opposed to the current supplied to operate the motor. When the motor is running light this current very nearly cancels out the current supplied, and therefore only sufficient is taken from the mains to supply the no-load losses. The actual resistance of a motor is very low; if it is held stationary, and this dynamo effect, therefore, is not present, it would take a very large current from the mains which would burn out the windings. Hence the necessity for a motor starter to bring the speed up gradually and create the opposing E.M.F. before the motor is connected directly to the mains.

The motor starter for a direct current motor consists of a resistance which is divided into steps and connected by a suitable switch so that on operating the starter the whole of the resistance is in the armature circuit, limiting the current flowing to sufficient only to cause the armature to rotate. As the speed of the armature increases, the back E.M.F. of the machine builds up, and opposing the current supplied, causes it to fall; the resistance is cut out in successive stages with a repetition of this effect at each step and gradually increasing speed until the motor is connected directly to the mains.

Motor starters are usually provided with automatic

attachments which switch off the motor in the event of overload or failure of the supply.

Alternating current motors are made with types of casing or enclosure similar to those of direct current machines, but are of a quite different electrical design.

The commonest type in general use is the induction motor. It consists of two parts: a stator corresponding to the field of a direct current machine and a rotor corresponding to the armature. The stator in appearance is rather like the armature of a direct current machine turned inside out, but the effect of the winding is to give a certain number of pairs of poles just as a direct current field. Passing the alternating current through this winding produces a rotating magnetic field having an effect exactly as if the field of a direct current machine were rotated mechanically, but in the rotating alternating current field there is no physical movement: the rotation is purely of the magnetic effect.

Now if a closed electrical circuit or winding is placed within this stator as a winding on the iron rotor, the combination will act as a transformer. The current induced in this way in the rotor will produce a magnetic field which will carry the rotor round in the same direction as the rotating field of the stator. The rotor will move at very nearly the same speed as the rotating field of the stator, only a slight *slip* being apparent.

This is a simple and general explanation of the working of an induction motor.

The winding on the rotor may consist of short heavy bars of metal simply short-circuited at their ends by brass or copper rings, as no connection with the mains is necessary, the current being induced by transformer action from the stator current.

On large machines the rotor is sometimes provided with a wire winding, the ends of which are brought to slip rings; this arrangement enables a resistance to be

inserted in the rotor circuit giving an opportunity for one method of speed control and starting.

The characteristic of the induction motor is very like that of the shunt direct current motor, namely, practically constant speed at all loads within its limit.

To reverse the direction of rotation of a three-phase motor all that is necessary is to change over two of the three mains connections to the terminals.

Reversing a single-phase motor is more complicated; this should only be done by the makers or an experienced electrician.

Alternating current motors, which are similar to direct current motors in that they are fitted with commutators, are made for special purposes; they can be wound for single-phase or three-phase circuits, but their use is very limited.

Synchronous alternating current motors have been mentioned; these in construction are similar to alternating current generators, and have the advantage, under certain conditions of the field, of a leading power factor which can correct the lagging power factor of induction motors which are served from the same mains. The drawback of the synchronous motor is that arrangements must be made to run it up by mechanical means to synchronous speed before switching on to the mains, and, further, a supply of direct current is necessary to excite the field.

Direct current motors can be wound to run at almost any speed within reasonable limits. The higher the speed the greater the output from the same frame. Consequently, a 10 h.p. motor at 1,500 r.p.m. would be much cheaper, probably little more than half the price, of a 10 h.p. motor at 500 r.p.m.

Alternating current induction motors are limited in their possible speed by the fact that the speed is governed by the rotating field. The rotation of this field being produced by the variation of and change

in the direction of the current in the stator, and the rate of this change is governed by the frequency and number of poles for which the stator is wound.

The full change or complete wave of an alternating current cycle is produced as follows: A conductor approaching and passing a north pole will have a current induced in one direction; it then approaches and passes a south pole and the half wave in the other direction is completed; therefore, one complete period represents a conductor passing one pair of poles.

Now 50 cycles per second is 3,000 per minute, and if the stator has one pair of poles (usually referred to as two pole) the magnetic field will rotate at 3,000 r.p.m. taking the rotor with it, and making allowance for slip, at about 2,850 r.p.m. As a magnetic circuit cannot have less than one pair of poles, this is the highest speed at which an induction motor can run on a 50 ~ circuit. Similarly, on a 25 ~ circuit the maximum speed would be about 1,450 r.p.m. As no number of poles is possible between two and four, the next highest speed for a 50 period motor will be about 1,450 r.p.m.; nothing intermediate between 1,450 and 2,850 being possible.

The following table gives the speeds available for motors on 25, 50 and 60 cycles per second alternating current circuits.

	2-pole	4-pole	6-pole	8-pole	10-pole	12-pole	14-pole	16-pole
25-period	1,450	720	480	360	285	230	—	—
50-period	2,850	1,450	950	720	575	480	410	360
60-period	3,500	1,720	1,150	850	700	575	485	425

In the above figures slip has been allowed for. The formula for ascertaining the r.p.m. of an alternating current induction motor is

$$\text{R.p.m.} = \frac{\text{periodicity} \times 60}{\frac{1}{2}\,(\text{number of poles})}.$$

This will give synchronous speed. The allowance for slip will vary with different makes of motor, but the actual speed will be from about 90 per cent to 95 per cent of synchronous speed.

The efficiency of electric motors is generally high, from 80 to 95 per cent at full load according to the size of the motor, the larger motors having the higher efficiency. Down to $\frac{1}{2}$ full load this figure will be fairly well maintained, but at a less load, say $\frac{1}{4}$ full load, a motor having a full load efficiency of 90 per cent would probably fall off to about 70 to 75 per cent.

At 100 per cent efficiency, 746 watts equals 1 h.p.; therefore, a direct current motor at 80 per cent efficiency, taking a current of 50 amps on a 400 volt circuit, will be giving an output of

$$\text{H.p. on D.C.} = \frac{\text{amps} \times \text{volts}}{746} \times \frac{\text{efficiency}}{100}$$

$$= \frac{50 \times 400}{746} \times \frac{80}{100} = 21\tfrac{1}{2} \text{ h.p. (approx.)}$$

If the motor is single-phase alternating current we must take the power factor into account; 0·8 is a good average figure for this; the formula will then be

H.p. on single-phase

$$= \frac{\text{amps} \times \text{volts} \times \text{power factor}}{746} \times \frac{\text{efficiency}}{100}$$

$$= \frac{50 \times 400 \times \cdot 8}{746} \times \frac{80}{100} = 17\tfrac{1}{4} \text{ (approx.)}$$

If the motor is three-phase alternating current we introduce the constant previously mentioned, 1·732; the formula is then

H.p. on three-phase

$$= \frac{\text{amps} \times \text{volts} \times \text{power factor} \times 1{\cdot}732}{746} \times \frac{\text{efficiency}}{100}$$

$$= \frac{50 \times 400 \times {\cdot}8 \times 1{\cdot}732}{746} \times \frac{80}{100} = 30 \text{ h.p. (approx.)}$$

If the cost of current is 2d. per unit, and the motor is running at a constant steady load, the cost per hour for running the motor in each of the above examples would be

D.C. motor (watts = amps × volts)

$$\text{cost per hour} = \frac{\text{watts} \times \text{cost of energy per unit}}{1000}$$

$$= \frac{50 \times 400 \times 2}{1000} = 40 \text{ pence.}$$

A.C. single-phase motor

$$\text{cost per hour} = \frac{\text{watts} \times \text{cost of energy per unit}}{1000}$$

A.C. three-phase motor

(watts = amps × volts × 1·732 power factor)

$$\text{cost per hour} = \frac{\text{watts} \times \text{cost of energy per unit}}{1000}$$

$$= \frac{50 \times 400 \times 1{\cdot}732 \times {\cdot}8 \times 2}{1000} = 55\tfrac{1}{2} \text{ pence}$$

Thus, the cost per horse-power hour for each motor works out at 1·86 pence.

The cost per horse-power hour is the same in all three cases in this example, but in practice this will not usually be so since it is improbable that the efficiencies will be identical. Also some supply companies penalize consumers whose average power factor is low, although a value of 0·8 would be tolerated. If trouble from this source is experienced it may be worth while installing

condensers to avoid incurring the penalty, but it is not usually worth while raising the power factor to unity.

Conditions may be such that it is possible to utilize a large synchronous motor for part of the power, in this case the installation of a motor of this type (which has a leading power factor) with or without the addition of a large condenser, may be useful. This correction of power factor is such an important point at which a saving may be effected, that Chapter XIII is devoted to the subject.

Large motors used for driving machinery should each be provided with an ammeter in circuit showing the current flowing. If the load is very variable, and it is required to know the cost of current consumed by that particular motor, an integrating wattmeter may be included in the circuit. It is not usual to fit an independent ammeter for each small motor, but in a factory a portable instrument should be provided so that tests may be taken from time to time; these tests will indicate if all is going well with the motor and the machinery which it is driving, and are also useful to the cost accountant in making his estimates for the allocation of the cost of power.

Electric motors may be direct coupled to machines. In this the driving spindle of the machine will run at the same speed as the motor and will be in line with the motor spindle; the drive will be either through a rigid or flexible coupling.

If the spindle or shaft to be driven must run at some speed other than motor speed, the drive may be by belt, chain, rope, or toothed, or other form of gearing; in this case the driven shaft will be parallel to but not in line with the motor spindle.

There are exceptions, but a drive between two shafts which are not parallel is usually inefficient and should be avoided if possible.

Summary of Chapter XI

The D.C. motor is exactly similar in construction to a dynamo.

The type of casing on a motor is dependent on the conditions under which it is used.

A totally enclosed motor is larger and more expensive than a protected type for the same output.

The shunt motor gives constant speed.

The series motor gives speed which varies with the load; the greater the load the lower the speed.

The compound motor combines the characteristics of the series and the shunt types.

Alternating current motors are usually of the induction type, having a characteristic similar to a shunt D.C. motor.

A.C. motors may be single-phase, two-phase, or three-phase.

Other types of A.C. motors are series, repulsion, and synchronous.

A synchronous motor is similar in construction to an A.C. generator. It is not usually self-starting, and requires D.C. for field excitation.

D.C. motors may be wound for any speed.

A.C. induction motors are limited in their speed range by the frequency.

One horse-power is equivalent to 746 watts, with 100 per cent efficiency.

To obtain watts on three-phase A.C., multiply amperes by volts × 1·732 × power factor.

The power factor, usually about 0·8, is caused by the lag of current in an induction A.C. circuit.

The power factor may be improved by inserting suitable apparatus in the circuit.

Motors may drive machinery by either direct, belt, or gear coupling.

Large motors should be provided with meters which will measure the power taken, and probably by indicating unusual conditions avoid breakdown.

CHAPTER XII

THE IMPROVEMENT OF POWER FACTOR

UNDER the new grid system, the power supply in this country will eventually become uniform, if not in voltage, in periodicity and the nature of the current.

As we have seen for long distance transmission, on account of the simple apparatus required to change the voltage, alternating current has great advantages over direct current. Three-phase alternating-current is more suitable for motors than single-phase alternating current, and requires less copper to transmit the same power. The lowest frequency which is high enough to ensure no visible flicker on the lights and which is convenient both for speed of motors and generators, is 50 cycles per second, and this is being generally adopted.

This standardization of supply considerably reduces the variety of stock to be carried by electrical manufacturers and merchants and further the reduced number of types should tend to decreased cost.

The drawback to the consumer of the change in many cases from direct current to alternating current is the question of power factor which applies to alternating current only.

The electrical end of a plant for the generation and transmission of power is so efficient, that power users who now draw their supply from a company and only distribute through their works are usually satisfied that there is no room for economy.

Many consumers have recently been transferred to alternating current mains and eventually practically all will have to take an alternating current supply; further, if they generate their own power and wish to use the outside supply as a stand-by, they must

generate alternating current. This change introduces a possibility of loss not experienced with the former supply and consequently liable to be overlooked. Both new and old consumers of alternating current, if they wish to secure the maximum economy and efficiency, should accordingly give serious attention to the power factor of their installation.

Exactly what is meant by the power factor is a little difficult to understand, and although it has

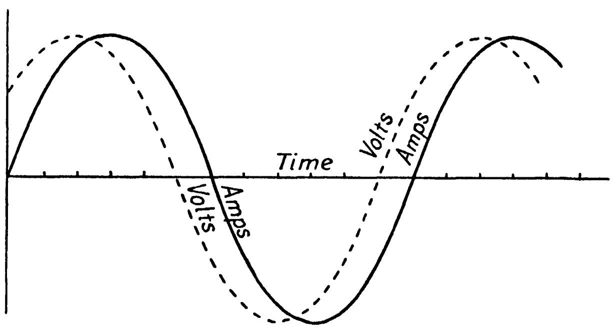


FIG. 30

already been outlined, recapitulation and further explanation may be useful.

Firstly, if the supply is for lighting with incandescent lamps and electric heaters, the power factor is probably so near to unity that there is no need for any action. If, however, the current is used for motors, arc lamps, certain types of electric furnace, or any apparatus containing electromagnets, a large proportion of the current taken is useless, and for a small capital outlay this can be avoided.

We have seen that alternating current voltage or power can be graphically represented by a curve which rises and falls (see page 125); either volts or amperes may be represented by different curves or the total watts by a combination of the two. The mechanical

energy taken at any particular instant is the product of the volts and the amperes at that instant.

When alternating power is used on an electromagnet the current (the amperes) seem to possess inertia, that is, the actual flow of current lags in time behind the pressure which produces it, and the point of the curve representing maximum current will be a little behind the point of the curve representing maximum volts. As the instantaneous energy is the product of the volts and amperes at a particular moment, energy measured by a wattmeter, which represents the actual energy used, will be less than the product of the rate of flow of current (amperes) and the pressure (volts). (Fig. 30.)

On a direct current supply the power taken is measured by a watt-hour meter which registers B.O.T. units or kWh. When alternating supply was first introduced the practice then was also to measure with a similar meter which gave the power that the consumer used. Later it was found that current was generated and passed through the mains which, while it was shown on the ammeters, did not appear as a factor on the wattmeter; this was the out-of-phase current due to the power factor of the circuit.

The amperes due to this out-of-phase current may amount to a very large proportion of the useful current, as the following table will show.

Power factor .	1	0·9	0·8	0·7	0·6	0·5	0·4	0·3
Percentage increase in current . .	0	11	25	43	66	100	150	240

Mains, switchgear, transformers, and other fittings have to be large enough to carry this increased current, which entails considerable capital investment which, in addition to being unproductive, limits the capacity of the system. The problem confronting the supply

companies was to secure a return on this invested capital. One way of dealing with it was to give a rebate to consumers with a good power factor, another is to make a fixed charge per annum according to the maximum kilo-volt-amperes load. Unlike the B.O.T. unit, the kVA includes the wattless current.

It is important to recognize the difference between B.O.T. units or kWh and kilo-volt-amperes (kVA).

The watt (W) is the product of volts and useful amperes, but it is a measure of power, and when a wattmeter is used on an alternating current supply it indicates the useful power and not the volts × total amps. Those amperes which are out of phase have no effect on the wattmeter, consequently they are not shown on the watt-hour meter which records B.O.T. units.

On the other hand the kVA meter shows the product of volts and amperes, and the reading includes the wattless current in addition to useful current.

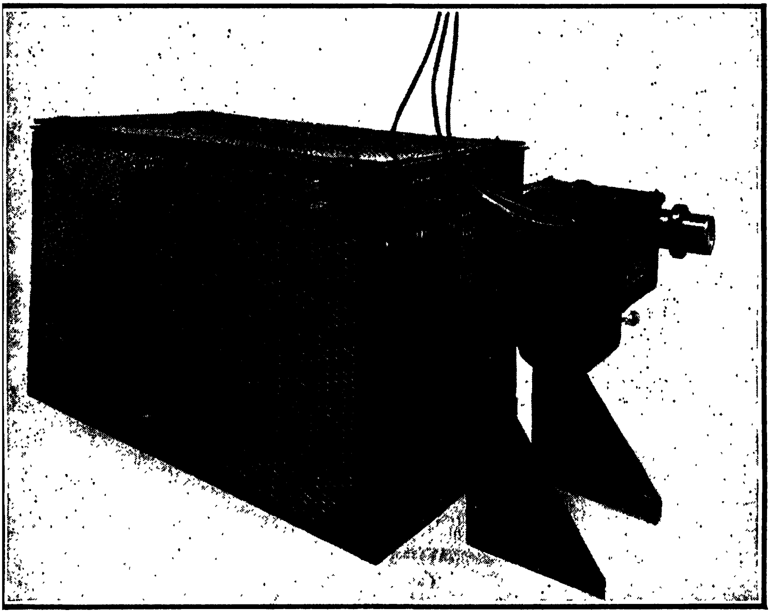
Just as most electromagnetic apparatus produces a lag in the amperes of the supply, so certain apparatus such as electrical condensers and over-excited synchronous motors will tend to produce a lead of the current. Now a forward lead alone of the amperes would have just as bad an effect as a lag, but if a lead can be introduced in sufficient quantity to balance the lag the current curve will coincide in point of time with the voltage curve, and the power factor will be raised to unity.

As previously stated, synchronous motors under certain conditions of field strength can be used to improve the power factor, but the simplest method is the installation of a condenser. (Fig. 31.)

An electrical condenser consists of a number of thin metal plates packed face to face and separated by insulating material; alternate plates are connected to opposite poles. To understand the working entails a knowledge of static electricity, but small condensers

will be familiar to all those who have a knowledge of wireless components. The condenser has no moving parts and, consequently, is not subject to wear or likely to get out of order.

The power factor of an installation is represented by the ratio of the actual power used, as measured in



(*Dubilier*)

Fig. 31

watts, to the apparent power supplied, measured as a product of volts and amperes.

Supposing you are taking useful current amounting to 800 watts, and on account of the power factor your meter shows 1,000 volt-amperes, your power factor is $\frac{800}{1000} = 0{\cdot}8$.

Another way of looking at this is that comparing

an alternating and direct current supply at the same price per volt-ampere, if the power factor is 0.8, 80 h.p. hours will cost, on the alternating supply, the same as 100 h.p. hours on the direct current supply; if the power factor is 1·0, the cost of power will be the same on either supply.

A power factor of 0·8 is very good for an alternating current installation, and would only generally apply if motors were running at full load; it may be as bad as 0·5, in which case the opportunity for saving is very much increased.

As will be understood, the economy that can be obtained by the correction of the power factor is capable of calculation, and as the cost of the necessary condenser installation will be known, the actual return can be stated in £ s. d. It is not usually advisable to correct to unity, as the size of the condenser necessary will increase as the square of the correction, consequently a figure of 0·95 is usually the aim.

The table given at top of p. 154 shows the economy which can be effected on a 100 kVA load at different values of power factor, assuming that the maximum demand factor is £6 per kVA and that the correction is made to 0·95.

If the supply company charge under the old method at so much per kilowatt hour with no kVA charge, there is no advantage in putting in a condenser unless the company will give a rebate for improved power factor. It is, therefore, advisable in such a case to approach the company and inquire what allowance would be made if the power factor were improved.

When the charge is made up of a small charge per unit and a fixed kVA maximum demand charge, it is the maximum demand charge which can be reduced. In the following examples: (A) is for a small motor working on the kVA maximum demand system, and (B) shows the conditions when a rebate is given.

Old Conditions Without Condenser			New Conditions Condenser Installed			
Load in kVA	Power Factor	Load in kW	Load in kVA	kVA Saved	Annual Saving	Cost of Condenser (Approx.)
					£ s. d.	£
100	0·90	90	94·9	5·1	30 12 –	46
100	0·85	85	89·7	10·3	61 16 –	65
100	0·80	80	84·2	15·8	95 – –	95
100	0·75	75	79	21	126 – –	106
100	0·70	70	73·8	26·2	157 4 –	120
100	0·65	65	68·7	31·3	187 16 –	120
100	0·60	60	63·2	36·8	220 16 –	140
100	0·55	55	58	42	252 – –	155
100	0·50	50	52·8	47·2	283 4 –	155
100	0·45	45	47·5	52·5	315 – –	175
100	0·40	40	42·1	57·9	347 8 –	175

Example A

A 3 h.p. motor running at full load for 300 eight-hour days, supply voltage 500 at 50 cycles, and a fixed maximum demand charge for current of £5 per kVA per annum, and a charge per unit of ¾d.

Assuming a power factor of 0·74 and a motor efficiency of 80 per cent—

	£	s.	d.
The fixed charge on the kVA demand . .	18	19	–
Charge for current	21	–	–
Total power bill . .	£39	19	–

When the condenser is installed the following will be the conditions if the power factor is improved to 0·95.

	£	s	d
Fixed charge	14	15	–
Energy charge	21	–	–
New total power bill . .	£35	15	–

The saving per annum is, therefore, £4 4s., and the cost of the condenser would be about £4 10s.

Example B

Assuming that the cost of supply is $1\frac{1}{8}$d. per unit, and that the charge is reduced in proportion to the power factor when it is above 0·85.

If the load is 300 kW and the power factor 0·7 operating for 52 weeks per annum, each of 45 working hours, the energy will be—

$$300 \times 45 \times 52 = 702{,}000 \text{ B.O.T. units.}$$

Cost of energy in £ per annum will be—

$$\frac{702000 \times 1\frac{1}{8}}{240} = £3{,}285.$$

If the power factor is raised to 0·95 this charge will become—

$$3{,}285 \times \frac{0{\cdot}85}{0{\cdot}95} = £2{,}940$$

showing a saving of £345 per annum.

The approximate cost of the condenser in this example would be £600; it would therefore be paid for in under two years, and thereafter there would be an annual saving of £345, or looking at it another way, the investment would produce over 50 per cent per annum.

These figures should be sufficient to convince that there is considerable room for economy in the consumption of alternating current on power supply.

Should the factory have a private power plant, at first glance it might appear that the installation of condensers would not show any advantage. This is not the case, as the wattless current costs money to distribute, although it is useless.

If the wattless current is eliminated by improving the power factor the total load is reduced by that amount. Cables, switches, and transformers carry less current, and if the transmission and distribution plant

is working at its maximum load and demanding extension, the introduction of condensers in the circuit may leave a sufficient margin to carry on without other alteration.

Summary of Chapter XII

The bulk of the electrical power supply in this country will soon be alternating current.

When the supply is A.C. a factor called power factor is introduced.

A low power factor means inefficiency and waste.

This waste can be avoided, as the power factor can be improved.

The installation of a suitable condenser will bring the power factor nearly to unity, which is the ideal.

The saving will repay the capital cost of such a condenser in from one to two years.

A condenser having no moving parts entails no maintenance expense.

If either you are a consumer from a supply company or generate your own power, the saving can be effected.

With a good power factor the maximum output of the power plant is increased.

The supply companies look with favour on any efforts made by the consumer to improve the power factor of his installation.

CHAPTER XIII

POWER DISTRIBUTION

In a small works, having one machine shop only, the distribution of power is almost without exception by means of shafting and pulleys.

The prime mover may be a steam engine, gas engine, or electric motor taking power from the mains.

A pulley is fitted to the shaft of the prime mover and from this, by means of an endless belt or rope, the power is transmitted to a long length of shafting which may extend the whole length of the shop and may be coupled to other long lengths which run parallel with the original shaft.

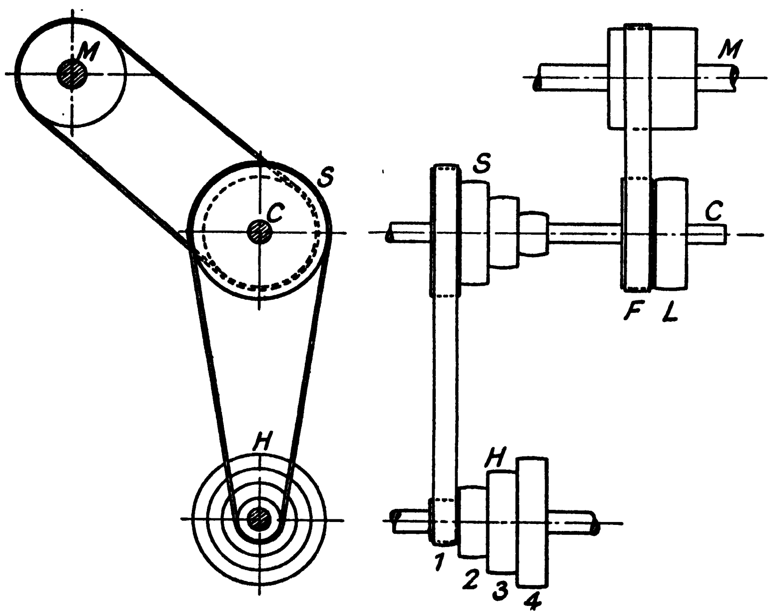
From these shafts the drive is taken by more belts, running over pulleys of suitable size, either directly to the machines or to countershafts from which the machines are driven.

Some machine tools run at constant speed, and others, which require variation of the driving speed, are fitted with gear to secure such variation as an integral part of the machine. All machines must be fitted with some device for starting and stopping; this may be a clutch, which also forms part of the machine itself.

Machines combining any or all of these features are driven directly from the main shaft. If, however, for the drive to the machine a step pulley is provided to give the various speeds or there is no provision for starting and stopping, a countershaft must be used between the main shaft and the machine.

An example of such a drive is the ordinary centre lathe. The main spindle or headstock of this machine is fitted with a stepped pulley. The countershaft is fitted with a similar pulley arranged with the step of

largest diameter opposite the smallest diameter step on the lathe pulley, and so that the smallest step on the countershaft is opposite the largest on the lathe. The belt driving the lathe can, therefore, be used on any pair of steps of the pulley which are opposite. If the belt is on the largest diameter step of the counter-



FIGS. 32 AND 33

shaft and the smallest of the lathe, the speed of the lathe spindle will be the highest possible; if at the other end of the step pulley the speed of the lathe will be the lowest possible. The usual method of arranging gear for starting and stopping the machine is to fit two pulleys of equal diameter side by side on the countershaft; one of these pulleys is securely keyed to the shaft and is known as the "fast pulley," and the other, preferably bushed with bearing metal or

fitted with ball bearings, is free to rotate on the countershaft; this is known as a "loose pulley."

The main shaft is fitted with a pulley which is slightly greater in width of face than the width of the combined faces of these two pulleys. The driving belt from the main shaft corresponds in width to the face of one of the pulleys on the countershaft. The driving belt is so arranged that by means of a fork it can be shifted so as to drive either on the fast or the loose pulley. When on the former the countershaft is rotated; when on the latter, owing to its being free on the countershaft, there is no rotation of the shaft, and consequently no drive to the machine. In place of the fast and loose pulley arrangement, frequently a clutch is provided.

Figs. 32 and 33 show a countershaft drive combined with stepped pulleys, and a calculation of the various speeds on this will be typical of all calculations for belt drives. In the drawing *M* is the main shaft, *C* the countershaft, *S* the stepped pulley on the countershaft, *H* the stepped pulley on the lathe, *F* and *L* the fast and loose pulleys.

Let the diameters of the stepped pulleys be 16, 14, 12, and 10 in., on each pulley; and the speed of the main shaft 300 r.p.m. It is required to run the countershaft at 200 r.p.m., and find the speed of the lathe spindle with the belt on either of the four steps.

In a belt drive between two shafts fitted with pulleys, the following is always true—

$$\text{Driving pulley diam.} \times \text{r.p.m} = \text{driven pulley diam.} \times \text{r.p.m.}$$

If the pulley on the main shaft is 10 in. diam.

$$10 \times 300 = 200 \times \text{diam. of } F \text{ and } L$$

$$\therefore\ 200 \text{ diam. } F \text{ and } L = 3000$$

$$\therefore\ \text{diam. of fast and loose pulleys} = \frac{3000}{200} = 15 \text{ in.}$$

The speed of H with belt in position 1 will be

$$16 \times 200 = 10 \text{ speed } H$$

$$\text{Speed of } H = \frac{16 \times 200}{10} = 320 \text{ r.p.m.}$$

In position 2

$$\text{Speed of } H = \frac{14 \times 200}{12} = 233\tfrac{1}{3} \text{ r.p.m.}$$

In position 3

$$\text{Speed of } H = \frac{200 \times 12}{14} = 171\tfrac{3}{7} \text{ r.p.m.}$$

In position 4

$$\text{Speed of } H = \frac{200 \times 10}{16} = 125 \text{ r.p.m.}$$

Pulleys should be slightly wider than the belt and only in exceptional cases should they be "flanged," that is, provided with a flange either on one or both of the edges to prevent the belt slipping off.

If a belt tends to run off the pulley either improper alignment or overload is indicated. A properly lined up belt drive, particularly if the pulleys are slightly "crowned" will always give satisfactory results, and the belt will run on the pulleys within the limits of the load which it will transmit.

A belt carrying a driving load always tends to run to the largest diameter of the pulley, consequently by making the face of the pulley slightly convex (this is called "crowning"), the belt will always run towards the centre. This crowning should only be small—about $\frac{1}{16}$ in. for every 6 in. of face—or the area of contact between the belt and the pulley face will be reduced, with consequent slipping.

Belts may be used crossed or open. The effect of crossing a belt is to reverse the relative direction of rotation of the two shafts.

Crossed belts are not so efficient as open ones, owing to the friction which takes place at the point of crossing. When laying out machinery, sufficient attention is not always given to this point, and very often by turning a machine round and using an open belt in place of the crossed, a more efficient drive may be obtained. In addition to the friction, with consequent loss of power in the crossed belt drive, the wear on the belt results in reduced length of life.

The power required to drive long lengths of shafting with its associated belting is considerable; even under the best conditions, probably 15 to 20 per cent of the total power delivered by the prime mover is absorbed by the mechanical transmission, and where the conditions are bad these figures are greatly exceeded.

To reduce this loss to a minimum, firstly, shafting must be kept in correct alignment; secondly, ball or roller bearings should be used; thirdly, shafting and pulleys must be balanced; and lastly, proper attention must be given to the tension on the belts and lubrication of the bearings.

The power absorbed in the transmission goes on all the time that the prime mover is in operation. Under full load it may not be a very high percentage of the power generated, but if only a few machines are working it may amount to perhaps 75 per cent of the total power.

The advantages of correct alignment are obvious, as if a shaft is out of line power is expended at every revolution in bending the shaft, and undue pressure is put on the bearings.

Ball and roller bearings reduce friction, are not likely to seize up, and further, as they require a little grease, perhaps only once in six months, save the cost of constant lubrication. As the diameter of a shaft to transmit a certain power depends on its r.p.m., the higher the speed the smaller the shaft, and with ball

or roller bearings higher shaft speeds are possible; there is also an economy in first cost.

Balance, while not so important as alignment, should receive attention, especially if the speed is high. A shaft and pulleys out of balance will whip and cause wear of the bearings and undulatory movement of the belts. This may cause a belt to leave the pulley, and in any case it will reduce the efficiency and life of the belt drive.

Too great a tension on a belt reduces its life and causes unnecessary wear on bearings.

An ideal belt drive is horizontal with the slack side of the belt uppermost. Other conditions cannot normally be avoided, but if possible, do not run a belt vertically: always make your drive as near as possible to the ideal.

Undoubtedly the most efficient method for the distribution of power to machines is the full electrical system in which each machine is fitted with its own driving motor properly proportioned to the power required, so that it is as often as possible running at its most efficient point. The losses in the transmission cables under these conditions are negligible; the motor is usually stopped with the machine, and its efficiency is probably never less than 75 per cent, and possibly in the large motors 80 to 90 per cent.

The spread of pure electrical transmission and drive in the factory in this country has been delayed largely on account of the great variety of types of electrical supply. Hitherto we have had D.C. or A.C. supply either at a great variety of voltages and the latter of single, two, or three phase and at varying frequency.

As motors of the same horse power but suitable for different supplies will vary considerably in size and detail, difficulty has arisen in building the motor as an integral part of the machine, and if supplied with the machine it has usually been as a separate unit.

This has encouraged a short-sighted policy on the

part of the purchaser who, in order to cut down his outlay, would arrange to drive the machine from his existing shafting and save the first cost of the motor; he probably has no idea, as he has never made tests of the losses in his mechanical transmission, of what interest he would receive on his small additional capital outlay, and the immediate cash saving to him is the only consideration.

The spread of the grid system, which is making a three phase 50 period supply universal for power purposes, has entirely altered this position, and there is now no reason why machines should not have electrical drives built in as a component part. Provision for a mechanical drive would be made only in special cases.

Another great advantage of the all-electric transmission is the facility it gives to the layout of the machinery in the direction of the flow of the work, as the necessity to locate machines to suit the run of the shafting is eliminated; further, a machine may be turned in any direction required for the most convenient operation, whereas if the machine is driven from line shafting its main spindle must be parallel with the shafting, and to avoid a crossed belt it should be so positioned that the machine spindle and shaft will run in the same direction.

Further, some machines, such as ones for grinding and polishing, and some types of woodworking machines, must run at a very high speed. If a high-speed motor is direct-coupled to the machine the gearing necessary to increase the low speed of the main shafting can be dispensed with; this also means a saving in first cost and increased efficiency.

Lastly, a stoppage such as the breaking of a main belt, transmitting power mechanically, will shut down the whole or a section of a works. If the machines are independently electrically driven, such hold ups are avoided.

As far as possible all shafts should be parallel; a change in direction of shafting entails the use of bevel gearing which at once introduces inefficiency. If mechanical transmission is in use and certain sections are not in continuous use, clutches should be provided so that the losses incidental to running a section of shafting, belts and countershafts light, may be avoided by putting a whole section out of action when the machines which it drives are not required,

Apart from some remaining installations in mills, rope gearing is in very little use at the present day.

The method of rope driving for mills is to use one large slow-speed engine having a flywheel perhaps 25 to 30 ft. in diameter, grooved to take from thirty to forty ropes. Built against the mill is a large chamber extending to the full height of the five or six floors of the building, the flywheel of the engine being at the bottom of this chamber.

The drive to each floor is taken from the flywheel by means of ropes which pass up this chamber directly from the flywheel to the driving pulleys which are on each floor.

This system is rapidly becoming obsolete; the modern method of fitting an independent motor to each loom or machine having such obvious advantages.

In an existing factory employing mainly mechanical power transmission and distribution, even if the prime mover is an electric motor, to change over to all electric suddenly would entail such dislocation of the organization and stoppage of work that it would almost always be impracticable; it is, however, quite possible to do the work gradually.

As new machines are bought or old machines replaced, they can be provided with independent motors. The shafting can be cut into sections and motors installed, each driving through the existing shafting a department or section of a department. Where the lay-out of the

works permits, machines may be grouped so that one motor drives a number of small machines; this is frequently quite an efficient arrangement, as its power may be suited to the normal working load.

Any method of combined mechanical and electrical distribution of power will depend on the nature of the machines to be driven, their location relative to the flow of the product, and other local conditions; each factory is a problem to consider as an individual case, and it is impossible to lay down anything more than general principles.

In laying out belt drives, it should be remembered that if the pulleys are too close together, and one is smaller than the other, the arc of contact between the belt and the small pulley will be reduced, and consequently greater tension will be required in the belt to transmit the power.

The larger the pulleys the less the tension required in the belt to transmit the same power as its velocity is increased; the amount to which the diameters of the pulleys can be increased is limited by the belt velocity, as, should this become very high, centrifugal force will tend to lessen the pressure between the belt and pulley, and extra tension will be required to overcome this loss.

The best adhesion, which means absence of slip with low belt tension, is obtained by the use of a single wide belt, and whenever possible this should be used in preference to a double belt, which consists of two layers of leather cemented together.

Machines are frequently put down and drives arranged by persons either ignorant of the simple principles ensuring efficiency, or seeing no particular benefit to themselves by taking the slight extra trouble necessary and realizing that getting the job done quickly may bring some commendation, proceed by the easiest methods to get the machine fixed and running.

Manufacturers of machines frequently do not provide a driving pulley suitable for the most efficient arrangement of drive, and improvements can often be effected in this direction.

Toothed gearing is mostly used for the transmission of power in the machine itself, sometimes as part of an engine. Two wheels having the same or different diameters or number of teeth either mesh together or are connected by a chain, also sometimes provided with teeth or which may have openings in the links which fit the teeth on the wheels.

Toothed gears are positive, that is, there is no slip, as with a belt drive, and consequently the relative positions between the driver and driven shaft are constant. This feature is sometimes very important when some other motion dependent on some coincidence of position of the two shafts at a given moment, has to come into action.

There is an additional advantage that toothed and chain gears occupy a much smaller space than a belt drive, both in diameter and centres, when transmitting the same power.

Providing that they are properly lined up and the centres of the driving and driven wheels correctly adjusted, this type of gearing, if well made, is very efficient. It is too expensive and limited in application for general power transmission, but where it is used the best test of its efficient running is the absence of undue noise and heat.

Summary of Chapter XIII

Power may be distributed mechanically by shafting and pulleys only.

Variations in speed required by the different machines is obtained by using different sized pulleys.

Variations of speed on one machine are usually obtained by stepped pulleys.

Machines having no integral device for stopping and starting,

and machines which require special external drives for speed variation, must be driven through a countershaft.

Stopping and starting is obtained by means of a clutch or fast and loose pulleys.

Pulleys should be wider than the belt and not usually flanged. Flanges cause wear at the edges of the belt.

Crowning assists in keeping the belt on the pulley.

Ball and roller bearings reduce friction losses.

Balance is important.

The pure electrical transmission is the most efficient, but entails high first cost.

The introduction of the grid system with consequent greater uniformity of supply is simplifying the problem of building driving motors into the machine.

All-electric transmission frequently permits of more efficient lay-out of machinery.

A breakdown of mechanical transmission frequently entails a stoppage of all machinery. With electrical transmission the effects of a breakdown are localized.

Rope driving is becoming obsolete.

Mechanical and electrical transmission may be combined; for example, a number of small or similar machines may be grouped and belt driven from shafting driven by an electric motor.

CHAPTER XIV

DISTRIBUTION OF STEAM AND GAS

In addition to the conveyance of steam from the boilers to the engines it is often necessary to transfer it to some distance away in the factory.

Steam is quite commonly used for general heating, and is frequently required in connection with various processes.

Cast iron was originally used for steam piping, but is now replaced by wrought iron. Copper is sometimes found in engine rooms; when polished its appearance is good, but it is too expensive for general use. The larger sizes of pipe are jointed by flanges at each end of the pipe secured, with suitable packing between, by bolts passing through the flanges; smaller pipes are jointed by screwed sockets in a similar manner to that adopted for gas piping.

The importance of suitable lagging, i.e. covering the pipe with heat insulating material, has already been pointed out; this is necessary in order to reduce loss of heat, with consequent condensation to water, to a minimum.

Leaky joints are also a fruitful source of loss. Insufficient room to allow for the expansion of the pipe due to heat or the lack of proper expansion joints is often the cause of leaks.

Steam pipes, as far as possible, should be so placed that they are not met by draughts of cool air.

In every steam pipe system it is necessary to insert steam traps in the line.

A steam trap is an automatic device which allows the water collected from condensed steam to drain away from the piping. This water may be delivered

through piping to the hot well and thus returned to the boiler. If this is done it should be so arranged that the discharge from each steam trap is visible. In this way an idea can be gained as to the amount of condensation taking place; also if the steam trap is not working properly and passing steam in addition to the water, the trouble is at once evident.

Steam for processes is seldom required at full boiler pressure, and it is usually taken through a reducing valve which will bring the pressure down to the amount required.

The cost accountant will require to know the amount of steam used for each process, and meters should be inserted in the distribution line. He should remember that the weight of a cubic foot in pounds will depend on its pressure; for instance, at 250 lb. per sq. in. pressure (above vacuum) a cubic foot of steam weighs 0·54 lb., at 25 lb. it will weigh only 0·06 lb.

Losses by friction of the steam in the pipes may become serious if pipes are too small. The usual method of determining the size is to arrange that the rate of flow does not exceed 6,000 ft. per minute. For very long runs pipes should be made larger so that the frictional loss does not become excessive.

For heating a factory, either steam or hot water is usually employed.

There are three usual methods of using steam for heating—

1. Live steam from the boiler.
2. Exhaust steam, sometimes used direct if the transmission distance is small, otherwise used to heat water which is circulated through pipes.
3. Steam at less than boiler pressure taken from a turbine at a point of suitable pressure. This steam is usually assisted by steam from the boiler during extra cold spells.

With regard to 3, as steam enters at one end of a

turbine at boiler pressure and leaves at the pressure of the condenser, and further, the diminution of pressure is gradual from one end to the other of the turbine, it is a simple matter to find a point at which steam can be extracted at any desired pressure.

The hot exhaust gases from a gas engine are sometimes utilized for heating water which is circulated for general heating purposes.

In whatever way the steam is obtained it must be distributed and made to give up its heat where required, either in long lengths of piping or in radiators.

The distribution piping is well lagged at points at which it is not required to give up its heat.

The rate at which heat is given up by the steam piping will vary with the difference in temperature between the steam and the air which it is heating. The whole problem of heating a factory is dependent on so many factors that it is very difficult to predetermine results.

For instance, the difference between the inside and outside temperature may be anything between about 60° F. and 0. Sometimes furnaces or other apparatus may be in operation, on other days they may be shut down. The friction losses in the machinery and some mechanical operations produce heat. The number of persons working each giving out, perhaps, 400 to 500 B.Th.U. per hour, will affect the temperature.

The air may be kept in circulation by moving machinery; large doors may be opened at frequent intervals for a period, at other times they are kept closed.

All these variable factors influence the temperature inside the building.

Once the desired temperature is obtained, all that is necessary is to make up the heat losses. These will take place by conduction through the walls, roof, glass, and wood doors. Ventilation is necessary, and the outgoing

air takes its heat with it. Who can say for certain how often the air in a shop is completely changed? It is usually assumed that the change takes place about once in every hour, although in some shops it may change much more frequently.

As we have already noticed, there is a very great difference in the heat conductivity of various materials, consequently the substances from which a building is constructed has a very great influence on the cost of heating, and in a climate where there are considerable periods of severe cold, it is advisable to give serious consideration to this point in order to prevent unnecessary waste of fuel.

Heat is transmitted more quickly through a plain brick wall than through a plastered brick wall. Concrete conducts heat away faster than bricks. Glass in windows is a better conductor, whilst metals such as corrugated iron, transfer heat so quickly that a considerable saving can be effected by lining with a good heat insulator.

The following figures will show the rate of loss of heat per square foot in B.Th.U. per hour through a 9-in. wall with a 20° F. difference in temperature between the outside and inside surfaces. Brick, 7; plastered brick, 4; concrete, 9. The average wood floor will cause a loss from below, of about 8 B.Th.U. per square foot per hour, but if there is a plastered ceiling below it this figure will be reduced to about 4 B.Th.U.

Two-inch thick doors and walls transmit about 6 B.Th.U. per hour per square foot of area.

The greatest loss of heat takes place through the glass of windows; the corresponding figure for these is 22 B.Th.U. per sq. ft. per hour, and corrugated iron, which will transmit 30 B.Th.U. per sq. ft. per hour.

All the above figures assume a difference in temperature of 20° F., and are approximate, as conditions will vary.

Heating engineers, in spite of their experience and accumulated data, cannot always predict the amount of heat required, but for the benefit of those who have to distribute a total cost of heating between different types of buildings, an example of a simple method of calculation may be useful, as the results would at least give figures showing a better proportion than mere guesswork.

Take as an example a building 100 ft. long, 50 ft. wide, and an average height of 20 ft., having concrete walls 9 in. thick and an unlined flat corrugated iron roof; assume that glass windows occupy 25 per cent, and wood doors, 2 in. thick, 5 per cent, of the area.

Total wall area = perimeter by height.
$= 2(100 + 50) \times 20 = 6{,}000$ sq. ft.

Area of doors, 5% of walls = 300 sq. ft.
Area of windows, 25% of walls = 1,500 sq. ft.
Area of concrete walls
$= 6{,}000 - 1{,}800$ = 4,200 sq. ft.
Area of roof 50×100 = 5,000 sq. ft.

Heat loss through

walls	$= 4{,}200 \times 9 =$	37,800 B.Th.U.
doors	$= 300 \times 6 =$	1,800 ,,
glass	$= 1{,}500 \times 22 =$	33,000 ,,
roof	$= 5{,}000 \times 30 =$	150,000 ,,
	Total	222,600 B.Th.U. per hour.

In addition, assuming that the whole of the air is changed twice per hour; the volume of the air contained in the building is

$$50 \times 100 \times 20 = 100{,}000 \text{ cub. ft.}$$

The B.Th.U. required to raise a quantity of air through 20° F.

$= \text{volume} \times \text{density of air} \times \text{rise in temp.} \times \text{sp. heat of air}$

$= 100{,}000 \times \cdot 083 \times 20 \times 0{\cdot}24$

$= 40{,}000$ B.Th.U. per hour (approx.) or

$40{,}000 \times 2 = 80{,}000$ B.Th.U. for two changes per hour

Therefore, the total heat lost will be

$$222{,}600 + 80{,}000 = 302{,}600 \text{ B.Th.U. per hour}$$

and this will be the heat required per hour to keep the temperature 20° above the outside temperature.

There are other factors which may influence the result. We know that a room full of people requires less heating than an empty room; this is because each person gives out from 400 to 500 B.Th.U. per hour. Mechanical and electrical losses usually appear as heat, therefore machining operations and heat from friction will all help.

If furnaces are used they will undoubtedly be a very considerable factor. Therefore, it is quite possible that the figure of 302,600 B.Th.U. will be reduced in actual practice.

In every method of steam heating the steam is allowed to condense, and the resultant water is returned to the hot well and thence to the boiler. The heat obtained, therefore, is the latent heat of evaporation.

When steam condenses at atmospheric pressure, 1 lb. will give up 966 B.Th.U. (This is the latent heat of steam); therefore, to provide 302,600 B.Th.U. per hour will require about 313 lb. of steam per hour.

It is interesting to see from the above calculations what a large quantity of heat is lost through the corrugated iron roof.

It should be noted also that, when heat insulating,

use should be made of the fact that air is a good insulator, provided it is shut up into compartments so that it cannot circulate and cool by convection.

A material such as sponge would fill such requirements. Loose wool with a plain painted outer covering would be good; slag wool, a fibrous material made from blast furnace slag, is excellent, but in positions where there is vibration it tends to crumble to dust.

We know that the temperature of steam depends on its pressure and the degree of superheat. At 300 lb. per sq. in. it will be over 400° F., and, as the tendency is to increase the working pressure, this temperature will become higher; inflammable materials for covering pipes are, therefore, somewhat dangerous, and should be avoided.

Carbonate of magnesia is frequently employed for covering steam pipes; it is fireproof and efficient, and there is on the market a number of proprietary coverings from which to select.

The distribution of gas in a factory calls for little description. Iron, not lead pipes, should be used. The usual method of jointing is by screwed sockets, although for very large sizes flanged couplings may be used.

Pipes must be sufficiently large to carry the maximum flow with little loss of pressure.

Gas may be looked upon as a method of distribution of heat, and the recent adoption of the "therm" as a unit for measuring the gas supply has simplified calculations as to the amount of heat obtainable.

Furnaces for heat treatment and stoves for enamelling and other processes are the usual applications of gas heating, although sometimes gas fires are adopted for offices.

Furnaces and ovens should be heat insulated outside to prevent loss of heat.

Gas is usually considered the best method of heating such appliances on account of its general cleanliness

and simplicity of control. The cost will depend on the price at which it is supplied, and comparisons will be made between gas and electricity by taking into account their relative cost.

In erecting gas mains of any size, arrangements should be made so that any condensed liquid will fall to a low point in the system, whence it may be drawn off.

Electricity for heating furnaces is coming into more general use. There is a complete absence of fumes, and the temperature can be controlled within very close limits.

At present the general method of obtaining the heat required is by passing the current through a resistance which becomes hot.

If alternating current is available, a form of transformer may be used in which the secondary consists of a heating element which obtains its heat from currents induced in it by the primary circuit. Developments are taking place in the direction of using very high frequency alternating current for the production of heat, and there is prospect of advance in this direction.

It is not economical to use electricity for general heating if steam is available.

The heating power in the steam can be used direct, whereas if electrical heating is adopted, the same power would have to pass through the engine and electrical generator, suffering loss at each stage. If electricity is generated cheaply from a water supply and there is no steam available, electrical general heating for a factory might be a reasonable commercial proposition.

Summary of Chapter XIV

Steam pipes must be covered to minimize loss of heat.

Leaky joints are frequently due to lack of provision for expansion.

Steam traps are used to extract condensed water from the pipe line; this water should be returned to the boiler.

Boiler pressure may be reduced by a "reducing valve."

The weight of a cubic foot of steam will depend upon its pressure.

Friction in pipes may cause loss.

Steam heating may be by live steam, exhaust steam, or steam "bled" from a turbine.

The heat required to maintain a given temperature in a workshop will depend upon its size and—

A—Loss of Heat—

1. The materials from which the walls and roof are made.
2. The area of the windows.
3. The rate of change of the air.

B—Gain of Heat—

4. The number of persons working.
5. The operations carried on.
6. The presence of furnaces.
7. The machinery in use.

The heating system must supply the difference between *A* and *B*.

In addition, the difference between the outside temperature and the temperature to be maintained is an important factor.

In steam heating systems the heat which is utilized is the latent heat of evaporation.

A porous material containing small air pockets is best for heat-insulating pipes.

This material should not be combustible.

Gas is used to convey heat to furnaces, etc.

Loss of heat from furnaces and ovens may be due to lack of or defective covering.

Electricity is also used for furnaces, but is expensive for general heating.

CHAPTER XV

COMPRESSED AIR

UNLIKE liquids, gases can be compressed to such an extent that at certain temperatures, under extreme pressure, a gas becomes a liquid.

The effect of pressure on a gas is given by Boyle's Law: the volume of a gas varies inversely as the pressure to which it is subjected, *if the temperature remains constant.* This means that if the pressure on a gas is doubled its volume is halved. In making measurements it must be remembered that the atmosphere at sea-level is already subjected to a pressure which varies with the height of the barometer, usually about 15 lb. to the square inch, and that pressure gauges show pressure above atmospheric; if, therefore, we take 1 cub. ft. of air at atmospheric pressure and compress it to 15 lb. gauge pressure, its volume will be halved as the pressure has been doubled; at a pressure of 45 lb. on the gauge (absolute pressure 60 lb.) its volume will be one-quarter, and at 105 lb. gauge (120 lb. absolute) its volume is reduced to one-eighth of the original. Advantage can be taken of the power of expansion of this air to operate machinery, such as presses, drills, and hammers.

The proviso "if the temperature remains constant" attached to Boyle's Law, is the reason for the greater part of the inefficiency of compressed air power generation and transmission.

There is another law, Charles' Law: If the volume of a gas be kept constant the pressure varies as the absolute temperature. (To obtain absolute temperature, add 461 to the reading on the Fahrenheit scale.) Supposing, therefore, a gas is heated from 0° F. (461

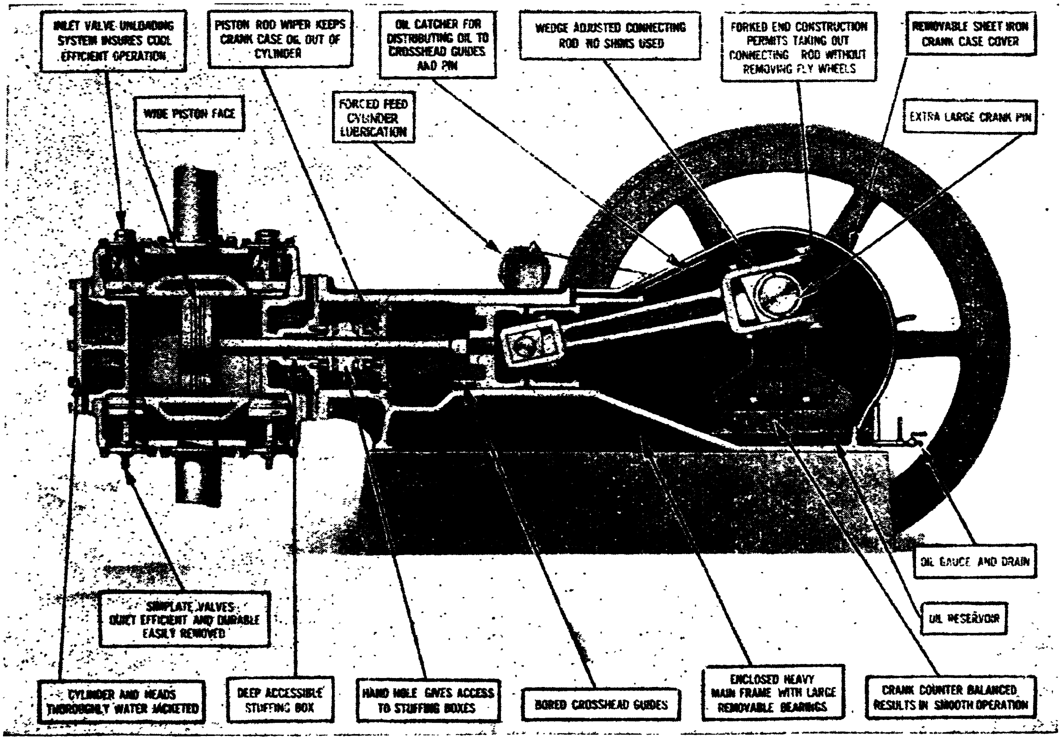
absolute) to 461° F. (922° absolute), that is, its absolute temperature is doubled, its pressure will be doubled.

Everyone knows that when a pump is used to blow up a cycle or motor tyre, after working for some time it becomes warm; this is due to the compression of the air. One way of looking at it is that the temperature of a body is due to the heat units which it contains, and its temperature can be raised by supplying more heat units. Now if we have a certain volume of gas containing a certain number of heat units it will be at a definite temperature. If the volume of the gas is reduced, those heat units are contained in a less space, and consequently the temperature rises. If the compression takes place very slowly the heat units will be transferred during compression to surrounding matter, and the rise in temperature will be very small. This is the reason why any increase in the speed of a pump used for compressing air will give rise to extra heating.

It is not commercially practicable to compress air so slowly that there is little increase in temperature, therefore, the expansion of the air due to increased temperature is a factor to be considered in the design and working of compressed air plant.

To transmit power by compressed air, the prime mover, which is usually a steam engine or electric motor, drives a pump, which may be of the reciprocating or rotary type.

The reciprocating pump (Fig. 34) is very similar to a steam engine in construction, with the exception of the valve gear which is usually of the plate or mushroom type and automatic in its action, i.e. no eccentric or cam gear is necessary for its action, although sometimes mechanically operated inlet valves are used. The suction opens and closes the inlet valve, and the pressure in the cylinder operates the exhaust valve at the right moment. Good valves will operate quickly and expose a large area for the passage of the air.

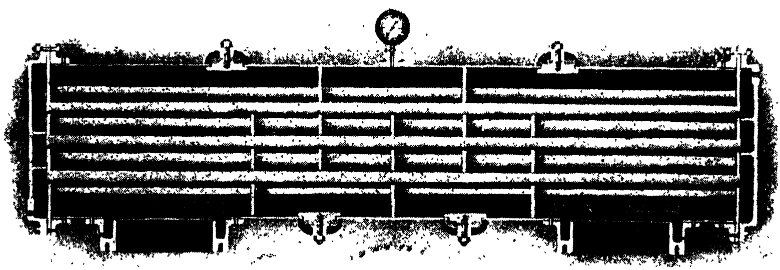


(*The Consolidated Pneumatic Tool Co., Ltd.*)

FIG. 34. SINGLE-STAGE BELT-DRIVEN AIR COMPRESSOR

A compressor has another feature not found on the steam engine, that is, an unloading valve. This valve opens when the pressure reaches a predetermined figure, and relieves the pressure on the compression side of the piston, in many cases allowing the piston simply to move air through the cylinder at atmospheric pressure, thus cooling the cylinder walls.

The compressed air passes through a drum container or receiver to the pipe line through which it is distributed to the points at which it is required.



(*The Consolidated Pneumatic Co., Ltd.*)

FIG. 35. SECTIONAL VIEW OF INTERCOOLER

Rotary compressors vary in design, and on test are not so efficient under ordinary circumstances as the reciprocating type.

We have already seen that the effect of the heat generated in the compression of air is that its volume is considerably increased, or, if expansion is not possible, its pressure is increased. When the air is compressed in the cylinder of the compressor it becomes hot, it cannot expand, consequently the piston has to work against a higher pressure than would be necessary if this heating could be avoided. The air on passing through the container and pipes for distribution will lose practically all the heat gained in compression, and with this heat it loses pressure; consequently, the

maximum pressure in the cylinder will be very much higher than the pressure in the pipe line. This unnecessary work is the reason for the greater part of the very poor efficiency of compressed air transmission.

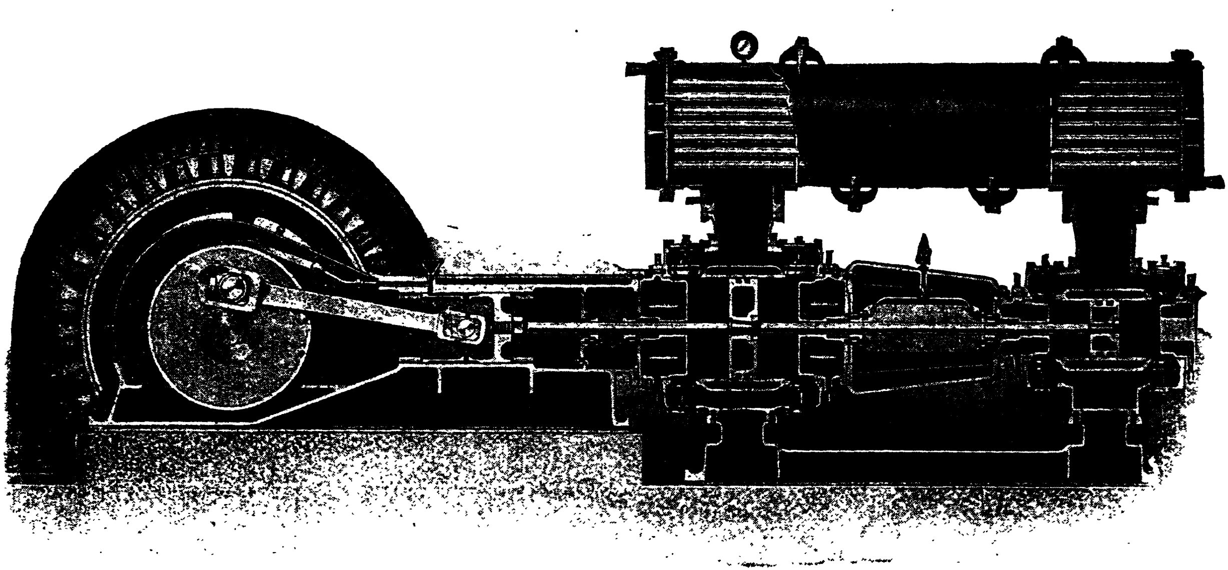
To a great extent efficiency may be improved by compressing in stages. When this is done the air is passed through one cylinder of a compressor, then through a cooler (Fig. 35) to reduce its temperature, and finally through another cylinder to increase its pressure to the desired amount. If pressure above 60 lb. per sq. in. is required, stage compression is always an advantage; the first cost of the plant is higher, but the increased efficiency repays the extra cost usually in about twelve months. The operating cost of a two-stage compressor is about 15 per cent less than that of a single stage for the same pressure.

Fig 36 shows a sectional view of a large electric motor-driven two-stage compressor.

Reverting to the relative merits of the reciprocating and rotary types of compressor, the latter is less efficient on account of leakage and increased friction. The rotary compressor is usually lower in first cost, and a two-stage rotary for a pressure of 100 lb. per sq. in. would be more efficient than a single-stage reciprocating type.

The cooler used between stages, called an intercooler, is similar to the steam condenser. A large drum is provided internally with a number of pipes through which cold water is circulated. The air to be cooled is passed through the drum which is of ample dimensions to ensure the slow passage of the air, and fitted with baffles to bring all the passing air in contact with the cold pipes.

The first necessity for transmission efficiency is pipes of ample size and freedom from sharp bends; the nature of the internal surface of the pipe also has an effect on the loss of pressure by which the efficiency is



(The Consolidated Pneumatic Tool Co., Ltd.)

FIG. 36. MOTOR-DRIVEN TWO-STAGE COMPRESSOR

determined. The second and more important point is freedom from leakage in the pipe system.

Escaping air is not visible, it has no smell, and may make little if any noise, and consequently is not detected as steam or gas would be. When it is realized that a small hole only $\frac{1}{16}$ in. in diameter at 100 lb. per sq. in. pressure will leak air equivalent to about 1 h.p., the importance of good jointing in pipes and connections to tools will be realized.

The man using a tool on a flexible pipe will not be particularly interested in saving air; when he changes the tool the free end of the pipe may pick up grit and spoil the joint and incidentally, perhaps, damage the tool, the tool may not make a proper connection with the pipe, or either may be dropped and the connection damaged.

Friction in pipes may be measured by loss of pressure. Leakage may be measured by closing the ends of the pipe system and measuring the time during which the pressure is maintained, or a rough test may be made by shutting off all machines and counting the power strokes of the compressor.

The intake of air to the compressor should be so arranged that the coolest and cleanest air available is used; in some cases provision is made for filtering and cooling the air at the suction point.

There is nearly always a certain amount of moisture in the air which will be deposited in the pipe system, consequently piping must be so arranged that this water drains to the lowest point or points from which it can be drawn off. Filters near the connections to tools will precipitate some of this moisture and clean the air finally before it is used.

We have seen that compressed air is an inefficient method of transmitting power; in fact, it is probable that the majority of compressed air plants do not operate at more than 10 per cent overall mechanical

efficiency. Mechanical efficiency is not, however, always a measure of commercial efficiency.

Compressed air is the only convenient motive power for all portable reciprocating tools such as rock drills, road breaking and demolition tools, portable riveting hammers used in ship construction, tank, boiler, and vehicle frame building, and constructional steel work; therefore, although the mechanical efficiency is low, it has an advantage in that it renders possible the use of special tools which cannot be operated in any other way.

One example of this commercial efficiency is in the use of portable riveting hammers which has reduced the cost of riveting such structures as ships and bridges by 40 to 60 per cent, when compared with hand labour which is the only possible alternative when rivets are used. It should be noted that for these purposes the tendency at the present time is to substitute welding for riveting, and the time will undoubtedly arrive when electric welding supersedes riveting.

It is never economical to perform hand work on material which can be conveniently taken to a fixed machine; for instance, hydraulic riveting by a machine is more efficient and possibly makes a better job than hand riveting, but the hydraulic riveter probably weighs as many hundredweight as the pneumatic hammer weighs pounds, and it would not be possible to move a ship or bridge to the hydraulic machine.

The pneumatic riveting hammer consists of a cylinder from 5 to 9 in. long in which there is a piston weighing from 1 to 3 lb. which is shot backwards and forwards by the compressed air controlled by a valve at one end, the number of strokes varying from 500 to 1,200 per minute.

The piston has an extension which strikes a blow for every stroke on a tool-holder in which can be fitted suitable rivet snaps and chisels. The tool weighs

from 20 to 35 lb., and can be easily handled by one man.

On constructional work, in addition to riveting, many holes have to be drilled or reamered in position, and the compressed air can be used for this operation. Air drilling machines are similar to very small piston-type steam engines, convenient for holding in the hand or at the least easily portable, but the latest innovation is an air drilling machine with a rotary motor.

The advantages of the use of such machines over hand drilling are obvious; the only commercial alternative is the portable electric drill which is certainly more mechanically efficient. It is, however, more liable to break down, and an electricity supply is not always conveniently to hand, whereas if the air is provided for riveting it may as well be used for drilling, as there is no electrical tool which is suitable for any but the very smallest riveting operation.

Pneumatic power is safe; explosions have occurred, and they are generally held to be due to the leakage into the cylinder of some oil having a flash-point lower than the high temperature reached during compression.

Such explosions are very rare and are not nearly so dangerous as a steam burst, as the air escapes and does no damage, whereas steam may cause scalding or fire.

Compressed air is used for purposes other than driving machinery; an instance is spray painting. An air pistol is used in which the passage of the compressed air draws up a continuous small supply of paint and blows it in the form of a fine spray with some force on to the surface to be painted. In the hands of a skilled operator much better work is possible than with a brush, and considerable time is saved.

A new development, in which compressed air is used, is the coating of wood and other materials with a thin

film of metal; this is known as "metallizing." The metal is melted at the point of a pistol, similar to the spray painting pistol, by means of an acetylene flame, and blown by compressed air on to the work.

For those more closely interested in the science of compressed air, it may be well to explain two terms frequently met in articles on the subject, viz. adiabatic and isothermal, compression or expansion.

Remember Boyle's and Charles's laws. Adiabatic compression or expansion takes place when the air is compressed or expanded without any transmission of heat to or from the air under treatment. This means that if during the compression stroke in the cylinder the air loses no heat to the cylinder walls but is raised in temperature by the compression, that no cooler is used and all the heat held until the air is expanded through the machine in which it is used and from which, owing to expansion, it will emerge at the same temperature as before it was compressed, the conditions are pure adiabatic transmission.

Isothermal compression and expansion take place when the temperature of the air is kept constant by the extraction or addition of the heat necessary for that purpose.

These two forms are theoretical extremes, and are never met in practice. If possible, isothermal compression would be more efficient than adiabatic. Actually the compressed air plant works at a point between these extremes, and the air exhausted from the tool or machine driven by compressed air on account of its expansion is much cooler than the surrounding atmosphere.

Summary of Chapter XV

The two laws affecting the compression of air are—

Boyle's Law. The volume of any gas is inversely proportional to the pressure to which it is subjected.

Charles's (sometimes called Gay-Lussac's) Law. If the volume of a gas be kept constant the pressure varies as the absolute temperature.

The compression of air increases its temperature.

Both reciprocating and rotary pumps are used for the compression of air, the former being the more efficient.

Stage compression means the attainment of the required pressure by means of several pumps dealing with the air in succession, the air being cooled between each stage. Stage compression may be used for pressures over 60 lb., and is always advisable for pressures over 100 lb. per sq. in.

Efficient transmission depends upon ample size of pipes, freedom from sharp bends, and absence of leakage.

The intake to the compressor should be so situated as to draw in the coolest and cleanest air available.

Compressed air transmission is mechanically of very low efficiency, but other advantages offset this drawback.

Adiabatic compression or expansion takes place when a gas is compressed or expanded without the gain or loss of heat (not temperature).

Isothermal compression or expansion takes place when a gas is compressed or expanded with the extraction or addition of sufficient heat to maintain a constant temperature.

CHAPTER XVI

HYDRAULIC POWER

HYDRAULIC presses, riveting and punching machines, and to a lesser degree cranes, lifts, capstans, and water-pressure engines, have their application in a factory doing heavy work, and where very great pressure is required there is often no alternative to the hydraulic press.

Hydraulic power may be transmitted by any liquid, but the use of water is almost universal, although oil under some circumstances may take its place.

Liquids are almost incompressible, that is, a certain volume of liquid will for all practical purposes occupy the same space under all conditions of pressure.

The principle of the hydraulic press is illustrated in Fig. 37. Two cylinders are fitted with pistons and connected by a short pipe. The space below the pistons is filled with water. The pistons make a perfect joint with the walls of the cylinders so that no escape of water is possible, and the area of piston R is, say, twenty-five times the area of piston P, which is made of 1 sq. in. area. The important principle on which hydraulic machinery is based is—

Fluids transmit pressure equally in every direction and this pressure acts in a direction at right angles to the surfaces pressed.

On applying a pressure of F lb. to the piston P, the whole of the surface of the liquid exerts a pressure of F lb. per square inch at right angles to the surface pressed. Therefore, as the surface of the piston R is 25 sq. in. in area it is subjected to a pressure of—

$$F \text{ lb. per sq. in.} \times 25 \text{ sq. in. area} = 25\ F \text{ lb.}$$

and accordingly a weight of F lb. on piston P will

support a weight of 25 F lb. on piston R. In hydraulic engineering the pistons, as shown, are usually made of the same diameter throughout and include the piston rod; the piston of the pump creating the pressure is termed the *plunger*, and the piston delivering the great force attained, the *ram*.

By the use of a pump plunger of small diameter and a very large diameter ram, an exceedingly high pressure may be produced even by hand operation.

In a hand-operated hydraulic press the pressure on

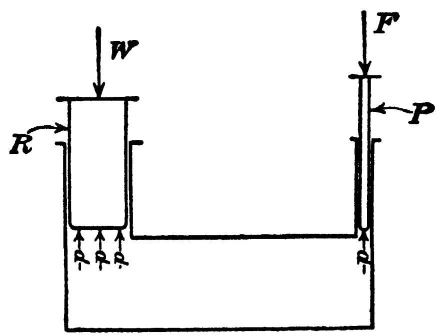


FIG. 37

the plunger is usually augmented by the addition of a lever giving a further mechanical advantage.

Fig. 38 shows a sectional diagrammatic view of a small hand-operated plunger pump supplying hydraulic power to a press.

The pump operating lever A provides the means to give by hand a reciprocating motion to the pump plunger B; at the same time, owing to the length of the lever A compared with the short distance from the fulcrum C to D, considerable mechanical advantage is obtained; for instance, if the distance CD is represented by 1 and the distance CP by 10, a pressure of 20 lb. at P will give a pressure on the pump plunger of 200 lb.

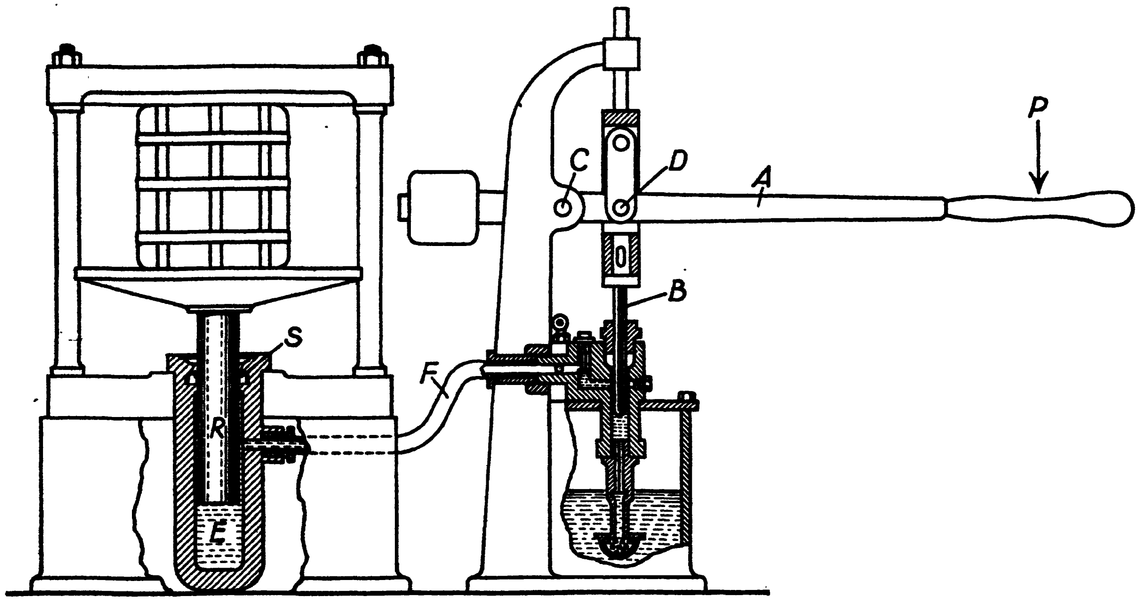
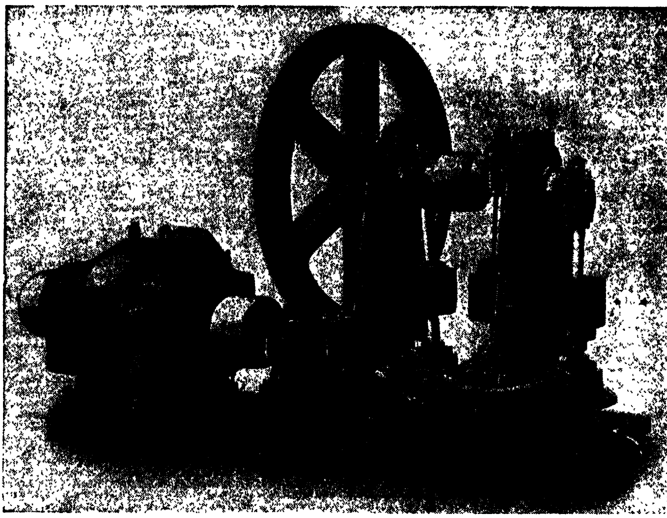


FIG. 38. HAND PUMP AND HYDRAULIC PRESS

The water is pumped into the cylinder of the press *E*, passing through the pipe *F*. This water, with little pressure, raises the ram *R* carrying with it the table on which is placed the work. As soon as the work is raised to the position at which the pressure is required to compress, shape, or draw the material, the high pressure is required and will be felt on the handle *P*.



(*Henry Berry & Co., Ltd.*)

FIG. 39. HYDRAULIC PRESSURE PUMP

If the area of the ram *R* is 100 times the area of the pump plunger, the pressure on the work will be 100 times greater than the pressure on the plunger; therefore, with a pressure of 20 lb. at *P* the total pressure on the ram will be 20,000 lb.

A relief valve is provided to pass the water back to the tank when the maximum pressure required has been obtained.

Where any considerable amount of hydraulic power

is required, electric or steam-driven pumps are employed. Fig. 39 is an illustration of an electrically driven three-throw vertical pump. There are three plungers, each operating in its own cylinder, driven from the same crankshaft.

Pumps must work at a low speed owing partly to the inertia of the water, but mainly in order to obtain the maximum pressure with the minimum power.

When the actual high pressure is on, there is frequently little movement of the ram, consequently the quantity of water used is small, and a low-speed pump will pass the water sufficiently rapidly. We know that, given the same power, the less the speed of a shaft the greater the torque; the pressure on the pump plunger is measured by the torque on the crankshaft, hence the necessity for the very large speed reduction obtained by the gear wheels shown in the illustration. A slow-speed motor could be provided, but again, as we have noticed, the slower the speed of an electric motor the larger it is, with consequent increased first cost.

When hydraulic machinery to any great extent is installed and required for frequent intermittent use, a hydraulic accumulator is provided.

As the pressure at any point in a column of water is proportional to its depth, *low* pressure can be stored by pumping water to a tank situated at a suitable height.

At a reasonably high pressure this is impracticable, consequently the hydraulic accumulator has been introduced.

The hydraulic accumulator consists of a vertical ram working in a cylinder, the cylinder being connected at the bottom to the pipe, running from the pump to the hydraulic machinery. The ram is weighted to give the desired pressure; if, for instance, the diameter of the ram is 12 in., and the pressure required is 2,000 lb.

per square inch, the necessary weight on the ram would be calculated as follows—

$$\text{Area of ram } 12^2 \times \cdot 7854 = 113 \text{ sq. in.}$$
$$\text{Load on ram } 2{,}000 \times 113 = 226{,}000 \text{ lb.}$$
or 101 tons (approx.)

When the water is not being used or the output of the pump exceeds the requirements of the machines, the surplus water passes into the cylinder of the accumulator and lifts the weighted ram.

An automatic arrangement is provided so that when the ram reaches the top of its stroke, the motor driving the pump is stopped or a relief valve opened which allows the surplus water to return to the tank, the former being the more efficient arrangement.

As the accumulated water is used by the machines, the ram falls, until at a predetermined point the motor is restarted or the escape of returned water is stopped.

The illustration (Fig. 40) shows a set of electrically driven hydraulic pressure pumps connected to a hydraulic accumulator, the pumps being automatically controlled.

The motor *A* is electrically connected to the contactor or controlling panel *B*, and through this panel to the switch *C* at the top of the accumulator.

When the motor is started, water is pumped into the accumulator, lifting it until the striker *D* comes into contact with the operating lever *F* of the switch *C*; this opens the switch and stops the motor.

As the water is used the accumulator falls until at a predetermined point the striker *E* comes in contact with the arm *G* of the switch *C*, automatically closing the switch and starting the motor. The positions of *D* and *E* can be arranged as desired to give any required stroke to the accumulator within its maximum limits.

As an additional safeguard, the accumulator is fitted with a deflecting valve *H* and knock-off rod *J*, so that

should the accumulator reach the top of its stroke and for any reason the automatic electrical control fails to act, the knock-off rod J lifts a circulating valve in the deflecting valve and enables the pumps to circulate

(*Henry Berry & Co., Ltd.*)

FIG. 40. HYDRAULIC PUMP, ACCUMULATOR, AND CONTACTOR GEAR

water instead of lifting the accumulator ram out of the cylinder.

The efficiency of hydraulic power transmission may be reasonably high. It is better than that of steam used for similar purposes, which is almost always intermittent work. Condensation in pipes is one of the heavy losses in steam transmission, and there is always

loss in heating up the cylinders before steam can be used, whereas with water power, condensation is impossible and no warming is necessary.

With long distance transmission the greatest loss is by friction in pipes. To secure the best results large pipes must be used and sharp bends avoided; the larger the pipes the lower the velocity of the flow, and consequently the lower the friction. Water, unlike gases, has, in popular phaseology, considerable weight, consequently every time the flow is started, considerable energy is consumed in putting it in motion owing to its inertia, and when the flow is suddenly stopped there may be a great shock owing to the sudden stoppage of motion of a heavy body.

Should an extra high pressure be required at infrequent intervals for special work, great economy in the amount of water used may be obtained by the introduction in the circuit of a differential accumulator or pressure intensifier.

Fig. 41 shows a pressure intensifier made by Messrs. Henry Berry & Co., Ltd.; it consists of a cylinder provided with two rams, one moving and one fixed in position by a cross head and steel tension bars. On admitting the low pressure water through a valve at the bottom, the moving arm is forced upwards, and the water displaced by the fixed ram is increased in pressure in proportion to the areas of the two rams.

Of course, only a small amount of water is available at each stroke, but the economy is great, as the general pressure for normal use on the hydraulic system can be considerably reduced.

Hydraulic power may be used for riveting, pressing, bending, drawing, and for many such operations is almost the only convenient and economical power available. It is also used to a limited extent in connection with heavy machine tools as an aid to their control when the manual labour would be very heavy.

Lifts and cranes are also often of the hydraulic type when the necessary hydraulic power is available.

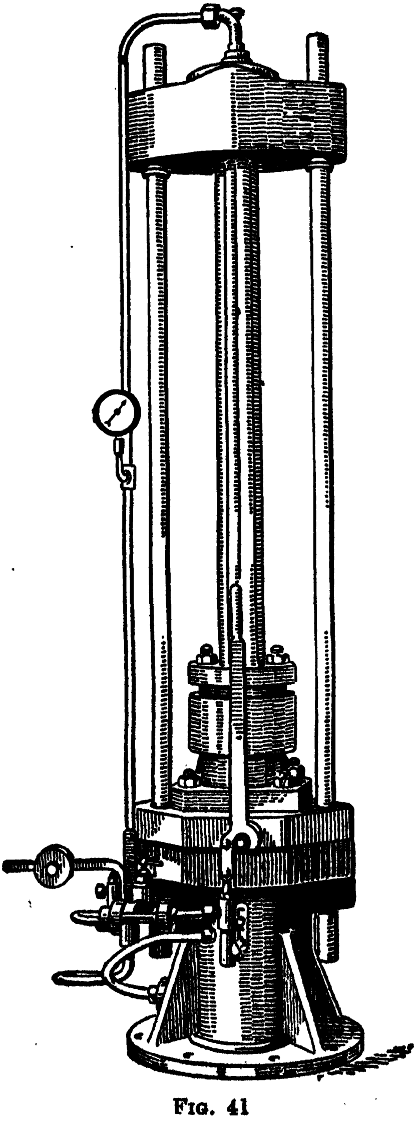


FIG. 41

Water pressure can be used to operate an engine of the reciprocating type in the same way as compressed air or steam, but is not so efficient for this purpose, as water under pressure has no power of expansion and great quantities would have to be passed to supply any large amount of power.

Hydraulic power is perfectly safe also, because water is almost incompressible; should a burst take place there is no explosion, as directly the water ceases to be confined all pressure is gone and the water runs harmlessly away.

For the same reason leaks should be attended to at once, as a small leak will cause a great loss, but as water is visible, providing the pipes are in view, a leak is easily detected and not liable to be overlooked as is the case with compressed air.

Summary of Chapter XVI

Hydraulic power is power transmitted by the flow of a liquid under pressure.

Water is the usual medium for the transmission of hydraulic power.

Liquids are practically incompressible (no power of expansion).

Fluids transmit pressure equally in all directions; the pressure on any part of a container is proportional to the area of that part.

Hydraulic pumps may be either hand- or power-operated, and the high pressure water obtained thereby is transmitted through piping to the machine at which it is required.

Water under pressure is stored in hydraulic accumulators.

Pressure may be increased for special purposes by means of a differential accumulator or intensifier.

Piping should be of sufficient size to reduce transmission losses to a minimum.

Reciprocating engines run on water pressure are not economical.

Hydraulic power is safe to use.

CHAPTER XVII

POWER AND THE COST ACCOUNTANT

POWER is a service and the cost is the total expense incurred up to the point at which it is used; thus, if power is available at any moment it may be required but is not used, expense is incurred and dealt with by recognized cost accountancy methods.

This point must not be overlooked, particularly in connection with electrical, steam, and compressed air power, as these cannot be conveniently stored in any quantity. Electrical accumulators may store a small amount of direct current power, but only for light loads; alternating current cannot be stored; compressed air can only be conveniently stored in small quantities, and steam, of course, condenses to water if allowed to cool.

If electricity is taken from a supply company's mains the cost will be made up from the charge made by the company, the maintenance and depreciation of the distribution system and the necessary motors for its conversion into mechanical power, together with the appropriate overhead.

The supply company may charge a flat rate per Board of Trade unit; there may be some sliding scale according to the consumption, but in any case the basis according to law is the B.O.T.U. In addition some companies make an additional charge per kVA maximum demand, and there may be other factors such as the price of coal.

When dealing with direct current the cost accountant can distribute his costs on the actual B.O.T.U. consumed by the motor, department, or other unit. This, for all practical purposes, will usually apply to

alternating current unless steps have not been taken to correct a possible very bad power factor.

When, however, the power is generated at the factory, the cost of generation must be shown in such a way that the management is warned of at least unusual inefficiency, and preferably of any inefficiency which is in continuous operation and which could be corrected.

For instance, if plant is available for a certain maximum output and only half that output is ever used, the service cannot be efficient as neither boilers, engines, nor generators will run so efficiently at half load as at full load.

The standing charges applicable to plant provided to meet occasional demand must be charged to that demand and not distributed over the whole of the motors in operation. For instance, a large machine taking considerable power may be introduced into a factory; the existing plant is not capable of supplying the additional power and more must be laid down. If the new machine is only in occasional use it would be obviously incorrect to absorb the standing charges of the additional plant by distributing them among the old machines or departments and thus increasing the cost of power generally.

Such a case might be met by the institution of some maximum demand charge per department or other unit, the details depending on the particular circumstances.

The data which the cost accountant should have from the boiler-house are as follows—

1. Amount of coal used—
   (*a*) for boilers under steam;
   (*b*) for boilers banked.
2. Amount of water used—
   (*a*) for steam raising, i.e. fed to boilers;
   (*b*) for auxiliary purposes.

3. Labour (properly detailed).
4. Times of boilers banked and under steam.
5. Records as follows—
   (a) Calorific value of coal, percentage ash.
   (b) Percentage of CO_2 in flue gases.
   (c) Steam pressure.
6. Total units generated (if transmission electrical).
7. Electrical energy consumed in the power house:
   (a) for lighting;
   (b) for motors.

In addition, if a number of boilers and engines are in use the accountant will require data for each unit as to the load and the period during which it is run.

These data will enable him to separate standing from running charges, and also keep an eye on the general running. The records will preferably be charted so that comparisons may readily be made.

If possible, it is also advisable to measure the steam supplied to each unit in order to compare the efficiencies. The total steam generated can, of course, be measured by the weight of feed water supplied to the boilers. If the feed water is measured in gallons, the conversion to weight is a simple calculation.

While meters may be installed either in departments or even at each motor, and the actual consumption of power ascertained, it is, of course, impossible to charge the true cost of power to each unit. As pointed out previously, the addition of a new machine to the plant may entail a great outlay in further generating plant to meet the demand, and in the same way frequency of demand or maximum demand will influence the distribution of the power costs, and exactly to what extent could not be economically determined.

This is only one instance from a number, particularly

in connection with services, where the cost accountant has to use his knowledge and common sense to make as equitable a distribution as conveniently possible, so that in recovering his power costs each unit is charged with a reasonable but not necessarily scientifically exact proportion.

The units consumed are the basis on which the charge is made, and as integrating electricity meters may be obtained so cheaply, there is no valid reason why they should not be installed at each point where it is desirable to make a measurement.

If meters are not available, a portable meter may be inserted in the circuit for a time under average conditions and an approximation made.

If no meters of any kind are available, the only guide is the plate on the motor or other apparatus which gives its full load consumption. "Needs must when the devil drives," but as some machines may be continuously overloaded and others lightly loaded, such indications are of little value and cost figures obtained by such methods would suffer considerably, and the small expense of some form of measurement would undoubtedly be offset by the advantages to be obtained.

So far in this chapter we have assumed that the steam raised is used to drive an engine, which in its turn drives a generator, and that the power is transmitted electrically. If the steam engine itself is used to drive shafting and the power is thus transmitted mechanically, as there is no practical way of measuring the power generated, and therefore no way of measuring it to departments or units, a rough estimate must be made based on the number and size of machines driven and the time for which they run.

Some information as to the power used in working certain machines may usually be obtained from the machine manufacturers, and a rough apportionment made on this basis.

It is quite usual to use a proportion of the steam raised for various heating and process purposes and to drive some tools directly, and the cost of this steam must be recovered from the users.

Steam used for heating, boiling, or cooking purposes may, of course, be metered; in the absence of meters exact calculation is impossible.

If from the nature of the apparatus the steam is condensed after use and the resultant water can be collected and measured or weighed, the problem is simple, as the weight of condensed steam is nearly enough the weight of steam used.

At this point it is advisable to remember the following properties of steam.

A given weight of water evaporates to an equal weight of steam.

The boiling point of water is 212°F. at atmospheric pressure only, viz. 15 lb. per sq. in. (approx.) (actual 14·72 lb. per sq. in.). The volume of 1 lb. of steam will depend upon the pressure.

The latent heat of steam is the amount of heat required to convert 1 lb. of water into 1 lb. of steam without change of temperature; it also varies with the pressure. This amount of heat will be given up by the condensation of 1 lb. of steam to 1 lb. of water. The total heat of evaporation is the sum of the latent heat and the heat added to the water and steam to change its temperature; it represents the heat units in the steam which have been used to raise the water from 32° F., and convert it into steam.

Steam in contact with boiling water from which it is being generated is known as saturated steam, and both the water and steam are at the same temperature. The temperature of the steam can be raised by superheating after it has left the boiler.

Many handbooks give the properties of saturated steam in full, but the following table in which, as far as

possible, the decimal points are omitted, will be useful to the cost accountant.

The pressure used in the table is absolute, but in the second column the approximate equivalent gauge pressure is given, assuming that atmospheric pressure is 15 lb. per square inch. This is sufficiently accurate for any calculations which the cost accountant may make.

Absolute Pressure	Gauge Pressure	Temp. Fahr.	Total Heat of Evaporation B.Th.U.	Latent Heat B.Th.U.	Volume per lb. in cubic feet
15	0	212	1,147	967	26
45	30	274	1,166	922	9·2
65	50	298	1,173	905	6·5
95	80	324	1,181	887	4·6
115	100	338	1,185	876	3·8
135	120	350	1,188	867	3·5
155	140	361	1,192	859	2·9
165	150	365	1,194	855	2·7
175	160	371	1,195	852	2·6
195	180	380	1,198	844	2·4
215	200	388	1,200	839	2·1
235	220	396	1,202	832	1·9
265	250	406	1,206	826	1·7
315	300	422	1,211	814	1·5
365	350	436	1,214	803	1·3
415	400	450	1,218	793	1·1

If the condensate cannot be measured some approximation may be made as to the amount of steam used for boiling, for instance, as the heat units required to raise the temperature of the liquid through the required number of degrees may be ascertained if its specific heat is known or approximated; the pressure at which the steam is supplied to the boiling apparatus may be measured or again approximated from the temperature of the steam at the point at which it enters.

The heat available in the steam may be ascertained from the table; if the steam is condensed only and heat is not taken from the condensate, the latent heat will be the figure; a simple calculation will then give an approximate figure regarding the steam consumption if the efficiency of the apparatus is 100 per cent. This, of course, is impossible, however well the lagging is put on, but some idea may be obtained in this way, and it is very useful for comparative purposes when a known quantity of steam has to be distributed between several similar units.

Steam is also used in connection with steam hammers.

The ordinary steam-forging hammer consists of a cylinder and piston arranged with its axis vertical. The steam above the piston supplies the force for striking the blow; the steam, when admitted below the piston, returns it to its original position ready for a fresh blow. The control of the admission of steam and the length of the stroke is by hand, with or without an automatic control which can be used as desired.

The blow of the steam drop hammer is due to the falling of the piston with its additional heavy weight; steam is normally only employed to raise the piston to a position ready for the next drop.

The old-fashioned steam helve hammer relies on the weight of the head for the blow, steam being used for the return stroke only.

The distribution of steam between a number of hammers may be made on the basis of the volume of the cylinder—

$$\text{Volume} = \text{area of the bore} \times \text{length of stroke}$$

—and the frequency of the blows, remembering that if steam is supplied to one side of the piston only, as in the drop hammer, each complete stroke uses the full volume of the cylinder once only; if steam is admitted to top and bottom for a complete stroke, the cylinder is

filled twice. If the mean pressure of the steam can be obtained, the actual amount used can be calculated, but as the operator may vary the length of stroke and frequency of blows, when meters are not available only an approximation can be made.

Compressed air may be metered to the tools or apparatus on which it is used; the amount taken by various tools will not vary very much from a standard which may be obtained from the makers. In the absence of a meter with which to test the tools, comparative tests can be made from time to time, and such tests are useful as they will indicate the condition of the tool tested.

A useful method of making such tests is to obtain a closed receiver which is air-tight and fill it with compressed air at, say, 100 lb. per sq. in. pressure. The tool to be tested can then be connected to the air in the tank and run until the pressure drops to, say, 80 lb. per sq. in.

The length of time for which the tool will run, while the pressure is falling, gives sufficient data for comparative purposes, and the total consumption may be distributed among the various tools according to the data thus provided.

The power used in compressing the air is easily ascertained if an electric motor is used; if the compressor is driven by a steam engine the consumption may be metered or approximated from the dimensions of the cylinders, the r.p.m., and the mean pressure in the cylinders.

A hydraulic pump for the supply of water for hydraulic power is usually driven in the same way as a compressor, and similar means would be adopted for ascertaining the power used.

To ascertain the consumption of water by hydraulic presses, the volume of the cylinder multiplied by the number of strokes will give the volume of water used.

or actual tests on an operation may be made by stopping the pump and measuring the amount of fall of the accumulator during the operation.

As an example, in a press used for a drawing operation, if the diameter of the ram of the accumulator is 24 in., and the fall is 3 ft., the amount of water used will be

$$\text{area of ram} \times \text{fall of accumulator}$$
$$= (\tfrac{22}{7} \times 12 \times 12) \times 36$$
$$= 452\tfrac{4}{7} \times 36$$
$$= 16{,}292 \text{ cub. in. or } 59 \text{ gal. (approx.)}$$

From data obtained by either or both of these methods the total cost of the hydraulic power may be reasonably distributed and recovered.

When dealing with compressed air, as it cannot be stored, if as in the case of steam a large compressor is installed to meet some infrequent demand, the standby charges must be properly allocated. In the case of hydraulic power, however, as the accumulator will meet the occasional extra demand, such charges can, under normal circumstances, be distributed evenly.

CHAPTER XVIII

UNITS OF MEASUREMENT

BEFORE any calculations can be performed or comparisons made, it is necessary to decide on some standard unit of measurement. Units will cover such values as weight, volume and size, and the necessary connecting links between these values which will necessitate the recording of other physical features.

The English units of pounds, feet, and gallons, are connected with each other, but the relations between the equivalent metric units are much simpler; for instance, the metre, the unit of length having been defined, the centimetre or $\frac{1}{100}$ part of the metre is easily ascertained; the centimetre squared provides a unit of area, and the centimetre cubed the unit of volume; 1,000 cubic centimetres (c.c.) being the volume of 1 litre. The unit of weight is the gramme, being, for all practical purposes, the weight of 1 c.c. of pure water. Therefore, as 1 litre is a volume of 1,000 c.c., it weighs 1,000 grammes or 1 kilogramme.

The English foot is an arbitrary length being one-third of the standard yard. Measurements of area may be made in square feet or yards.

The unit of weight, 1 lb., is another arbitrary unit which is connected with the unit of volume, 1 gal., as 10 lb. of pure water measure 1 gal.

In olden times various standards were used in different parts of the country; as trade increased the need was felt for more universal accuracy, and eventually fairly accurate standards were made, for instance, the standard yard is indicated by two marks on a metal rod at the Houses of Parliament, other

standards being in Trafalgar Square and at the Royal Observatory, Greenwich.

Before the advent of exact sciences and engineering, such standards sufficed, but later the need for more accurate measurement was found, and the standard yard of 36 in. was defined as such, that a pendulum vibrating seconds of mean time at a temperature of 62° F. at sea-level and the latitude of Greenwich, has a length of 39·1393 in. This connects the measurement of length with that of time, which, as is generally known, is based on the duration of the day and night or revolutions of the earth on its axis.

Finally, as the need for a more accurate standard has arisen, the wave-length of light from the element cadmium has been adopted as a reference for the standard of length.

The necessity for more accurate standards has arisen as facilities for accurate measurements have improved, but absolute accuracy of measurement is not yet attainable, although an accurate unvarying standard has been set up.

For instance, we may refer to the diameter of a machined steel bar as being exactly 1 in.

As steel expands and contracts with variations in temperature when giving the dimension to such an extreme we must specify at what temperature it is measured.

Further, as it is impossible to machine material to an exactly circular section, although it may be so near that ordinary means of measurement do not show the inaccuracy, it is impossible to machine a steel bar to exactly 1 in. in diameter.

In all but general statements in which sufficient commercial accuracy is implied, it is therefore necessary to specify the standard of accuracy.

It is important to remember that nothing is gained by attaining greater accuracy than is demanded by

the circumstances. It would not pay the grocer to take the necessary steps to ensure that he could dispense 112 separate pounds of tea from a quantity of 1 cwt., and in the same way in machining operations they should be taken only to such a degree of accuracy as is necessary. For instance, it is possible to turn on a lathe to within $\frac{1}{1000}$ of an inch of accuracy on a certain diameter, but it will be very much cheaper to finish to within $\frac{1}{200}$; after turning by grinding, a diameter may be finished to within $\frac{1}{10000}$ of an inch, but this entails an additional operation and an expense out of all proportion to the increased accuracy which may not be demanded.

Cost accountants are faced with the problem as to the necessary accuracy of the figures which they obtain for time and material and the distribution of overhead expenses. The more staff and time employed on their measurement the more accurate the figures should be, but this is all extra expense, and the economical point is that at which sufficient commercial accuracy of the desired information is obtained with the minimum of expense.

There are various ways of indicating the accuracy of figures; the value is always between two amounts, the difference between these amounts being known as the limit.

When decimals are employed it is usual to assume that the last decimal point indicates the limit, thus—

1·02 in. indicates that the actual dimension lies between 1·015 in. and 1·025 in., the limit being 0·01 in.

Another method is to give both dimensions; for instance, a dimension to the above limit may be written on a drawing $\frac{\text{H. } 1{\cdot}025''}{\text{L. } 1{\cdot}015''}$, H. and L. representing "High" and "Low"; or the dimension may be written 1·020″ ± 005.

In machine shops sometimes a standard set of limits,

such as the "Newall," is employed, in which case a letter may be employed to show the standard of accuracy set up in the table.

Sufficient has been said to emphasize the fact that absolute accuracy is theoretical only, and in a factory any nearer approach to accuracy than is demanded by commercial practice and the actual circumstances is waste.

The British units are based on the foot, pound, gallon, and hour; these, as has already been shown, are all related.

MECHANICAL UNITS OF MEASUREMENT

Mechanical Work. The unit of work is the foot-pound, and is the work done when a resistance equivalent to 1 lb. weight is overcome through a distance of 1 ft.

To find the number of units of work performed in an operation, multiply the resistance in pounds P by the distance in feet S.

$$\text{Mechanical work} = P \text{ (resistance)} \times S \text{ (distance)}$$

Power. Power is the rate at which work is performed; the unit is the horse-power which is equal to 33,000 ft. lb. per minute.

$$\text{Horse-power} = \frac{\text{resistance} \times \text{distance per min.}}{33000}$$

Force. Force is that which moves or tends to move a body, or which changes or tends to change the motion of a body. The unit of force is the pound, and a force is measured by engineers in Britain by the number of pounds which it would support against the pull of gravity; thus, a force of 50 lb. would sustain a weight of 50 lb. when the weight is acted on by gravity alone.

Velocity or Speed. Velocity is the speed at which a body moves. Velocity through space is measured in

feet per minute or sometimes miles per hour. The speed of rotating bodies is usually measured in revolutions per minute.

Torque. Torque or turning moment of a force about a point is the product of the force in pounds and the perpendicular distance in feet from the point to the line of action of the force.

Torque is usually expressed in lb.-ft. to avoid confusion with ft.-lb., the unit of work.

When more convenient, torque is sometimes expressed in lb.-in.

Temperature. Temperature is measured in Britain by degrees according to Fahrenheit's scale, and indicates the hotness of a body. The Fahrenheit scale is based on an arbitrary measurement calling the temperature of a melting mixture of ice and salt 0°, and the temperature of boiling water at a certain pressure 212°. The centigrade scale of Celsius is more convenient, as it is divided into 100° between the melting-point of ice and the boiling-point of water at atmospheric pressure.

For some measurements *absolute* temperature is required. The absolute zero is that point at which a body has no heat; it has been calculated by scientists to be 461° below zero on the Fahrenheit scale, or 273° below the Centigrade zero.

To express degrees F. in absolute temperature, it is therefore necessary to add 461 to the thermometer reading. Thus, the melting-point of ice is 493° F. absolute, and the boiling-point of water 673° F. absolute.

Heat. The unit of heat is the amount of heat necessary to raise the temperature of 1 lb. of water through 1° F.; the particular degree chosen when extreme accuracy is desired is between 39° and 40° F. This amount of heat is known as the British Thermal Unit (B.Th.U.). The THERM is equivalent to 100,000 B.Th.U.

Pressure. The pressure of a liquid or gas confined in an enclosed space and subjected to compression is usually expressed in pounds per square inch or sometimes in tons per square inch. There is a constant pressure of the atmosphere surrounding the earth which averages about 15 lb. per square inch. The pressure, as shown on a pressure gauge, indicates the pressure above atmospheric pressure. Absolute pressure is expressed by the addition of atmospheric pressure to the gauge reading.

Electrical Resistance. The Ohm (R) is the unit of electrical resistance, and is represented by the resistance of a column of pure mercury, 14·4521 grammes in weight of even cross-section, and having a length of 106·3 centimetres at 0° C.

Electrical Current. The Ampère (I)* is the unit of the rate of flow of electrical current and is defined as that current which, when passing through a solution of pure silver nitrate in water, deposits silver at the rate of 0·001118 grammes per second.

Electrical Pressure. The Volt (E.M.F.) is the unit of electrical pressure and is ·697 of the voltage given by a Clark primary cell made to Board of Trade specification.

The relation of the electrical unit to one another is

$$\text{Amperes (current)} = \frac{\text{electromotive force (volts)}}{\text{resistance (ohms)}}$$

Electrical Power. The watt (W) is the unit of electrical power in any circuit; for D.C. the power is equal to the volts multiplied by the amperes, 1 watt being equal to 1 volt × 1 amp.

$$\text{Power (watts)} = \text{pressure (volts)} \times \text{current (amps)}.$$

* *Note.* Amperes is sometimes in old books represented by C, and the above formula (Ohm's Law) given as $C = \frac{E}{R}$; $I = \frac{E}{R}$ is the modern form.

When dealing with great power, 1,000 watts, 1 kilowatt is used as the unit.

$$1 \text{ horse-power} = 746 \text{ watts.}$$

Electrical Power Supply. In order that a supply company may charge, and to know the total energy over a period, it is necessary to know the amount of the power and the time for which it is used. The unit adopted for this purpose is the Board of Trade Unit (B.O.T.U.), this unit being the kilowatt-hour, and is the product of the rate of doing work in kilowatts by the time in hours.

$$\text{B.O.T.U.} = \text{kW} \times \text{hours.}$$

Another unit sometimes used in connection with electricity supply is the kilovolt-ampere (kVA), which is the product of volts and amperes divided by 1,000.

$$\text{Kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1000}$$

The kVA is used for calculating the maximum demand.

Gas Supply. The old system of charging for gas was per unit of 1,000 cub. ft. This has now been altered, the volume depending on the heating value of the gas. The present unit is the therm.

Steam. The unit adopted for steam is the pound weight. The reason for this is that the volume of steam will change with temperature and pressure, whereas 1 lb. of water will always produce 1 lb. of steam.

Efficiency. The efficiency of a machine is the ratio which the useful part of the output bears to the gross input. Efficiency is usually expressed as a percentage of the input.

Thus, if 1,000 watts is taken from the mains by an electric motor and it is giving 1 h.p., the electrical

equivalent of 1 h.p. is 746 watts; therefore, the efficiency is

$$\frac{746 \times 100}{1000} = 74{\cdot}6\%$$

Whenever transformation of energy takes place loss occurs, and is usually in the form of heat developed by friction. For example, when any form of gearing is used to change the r.p.m. of a shaft, there is friction in the bearings; if toothed gears are used, friction at the points of contact of the teeth; and if belt gearing, slip between the belt and pulleys and bearing losses. The aim of the designer is to reduce these losses to a minimum, but 100 per cent efficiency is impossible.

The electrical transformer has no moving parts and consequently no friction losses, but a small percentage of the current is used for the reversal of the magnetization of the iron causing a re-arrangement of its constituent molecules; slight electrical eddy currents are induced in the iron, and small losses occur due to the electrical resistance of the windings. These losses all appear as heat, hence the necessity for oil cooling of large transformers, although their efficiency may be over 97 per cent.

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